ALUMINUM DESIGN MANUAL

2010

The
Aluminum
Association

ISBN: 978-0-9826308-0-8

2010 Aluminum Design Manual

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FOREWORD

The *Aluminum Design Manual* includes an aluminum structural design specification and accompanying commentary, a supplemental design guide, material properties, properties of common shapes, design aid tables, and illustrative design examples.

This edition of the *Aluminum Design Manual* is the product of the efforts of the Aluminum Association Engineering and Design Task Force, whose members are listed below.

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Please check www.aluminum.org for postings of 2010 *Aluminum Design Manual* errata.

Aluminum Design Manual

PART I

Specification for Aluminum Structures

Foreword

The first edition of the *Specification for Aluminum Structures* was published in November, 1967, followed by subsequent editions in 1971, 1976, 1982, 1986, 1994, 2000, and 2005. This ninth edition of the *Specification* combines the previously separate allowable stress and load and resistance factor design specifications. The *Specification,* developed as a consensus document, has been completely reorganized and includes new or revised provisions concerning

- safety and resistance factors
- design for stability
- adding 6005A-T61 and 6082-T6
- notch sensitivity of 6005-T5 and 6105-T5
- a glossary
- shear yield strengths
- shear strength of tubes
- screw pull-over
- screw slot pull-out strength
- serviceability
- evaluating existing structures
- axial compressive strength of complex cross sections
- fatigue strength of light pole bases
- members subject to torsion
- local buckling strength of welded elements
- design for fire conditions
- design of braces

The Aluminum Association gratefully acknowledges the efforts of the Engineering Advisory Committee in developing this edition of the *Specification.*

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Guidelines for the Preparation of Technical Inquiries on the *Specification for Aluminum Structures*

Technical inquiries to obtain an interpretation or request a revision to the *Specification for Aluminum Structures* should be directed to:

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Comments on other parts of the *Aluminum Design Manual* are also welcome.

Inquiries should be typewritten and include the inquirer's name, affiliation, and address. Each inquiry should address a single section of the *Specification* unless the inquiry involves two or more interrelated sections. The section and edition of the *Specification* should be identified.

Requests for interpretations should be phrased, where possible, to permit a "yes" or "no" answer and include the necessary background information, including figures where appropriate.

Requests for revisions should include proposed wording for the revision and technical justification.

Inquiries are considered at the first meeting of the Engineering and Design Task Force following receipt of the inquiry.

I
Specification for Aluminum Structures

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Numbers in parentheses after section numbers are corresponding ADM 2005 section numbers.

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Symbols

The section numbers in which the symbol appears is given in parentheses after the symbol.

A_b = nominal cross-sectional area of the bolt (unthreaded body area) (J.3.8.4)

A_e = net effective area (D.2, D.3.2)

A_f = area of the member farther than $2c/3$ from the neutral axis, where c is the distance from the neutral axis to the extreme compression fiber (F.9.2)

A_g = gross cross-sectional area (B.5.4, D.2, E.3, E.3.2, E.4.1, E.4.2, E.5, E.6.2, F.2.2.3, F.8.1.1, G.1, G.3)

A_{gc} = gross cross sectional area of the element in compression (B.5.5)

A_{gt} = gross cross sectional area of the element in tension (F.8.1.2, J.6.3)

A_{gv} = gross area in shear (J.6.3)

A_i = area of element i (E.4.1)

A_L = cross-sectional area of the longitudinal stiffener (B.5.5.3)

A_n = net area (D.3.1, D.3.2)

A_{nt} = net area in tension (J.6.3)

A_{nv} = net area in shear (J.6.3)

A_{pb} = projected bearing area (J.7)

A_r = root area of the screw (J.5.5.3, J.5.6.3)

A_s = area of the intermediate stiffener (B.5.4.4)

A_{sn} = thread stripping area of internal thread per unit length of engagement (J.5.5.1.1)

A_w = web area (G.2)

A_{we} = effective area of a weld (J.2.1.2, J.2.1.3, J.2.3.1, J.2.3.2)

A_{wz} = cross-sectional area of the weld-affected zone, which extends 1 in. (25 mm) to each side of the centerline of a weld (B.5.4, D.2, E.6.2, F.8.1.1, F.9.2, G.1)

A_{wzc} = cross sectional area of the weld-affected zone in compression (B.5.5)

A_{wzt} = cross sectional area of the weld-affected zone in tension (F.8.1.2)

B_{br} = buckling constant intercept for bending compression in flat elements (B.4, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, F.4.2, F.5)

B_c = buckling constant intercept for compression in columns and beam flanges (B.4, B.5.4.4, E.3, F.2.1, F.3.1)

B_p = buckling constant intercept for axial compression in flat elements (B.4, B.5.4.1, B.5.4.2, B.5.4.6, F.5)

B_s = buckling constant intercept for shear in flat elements (B.4, G.2, G.3, H.2.1)

B_t = buckling constant intercept for axial compression in curved elements (B.4, B.5.4.5, F.6.2)

B_{tb} = buckling constant intercept for bending compression in curved elements (B.4, F.6.2)

C = torsional shear constant (H.2.2)

C_b = coefficient that accounts for moment gradient along a beam's length (F.1.1, F.1.1.1, F.1.1.2, F.2.1, F.2.2.3, F.2.3, F.3.1, F.4.2, F.5(c), F.5.1, F.5.2, 6.3.2.1)

C_{br} = buckling constant intersection for bending compression in flat elements (B.4, B.5.5.2, F.4.2, F.5)

C_c = buckling constant intersection for compression in columns and beam flanges (B.4, B.5.4.4, E.3, F.2.1, F.3.1)

C_d = brace coefficient (6.3.1.1, 6.3.1.2)

C_f = coefficient used to determine the allowable stress range for fatigue (3.2, 3.3)

C_n = correction factor for the number of tests (1.3.2)

C_p = buckling constant intersection for axial compression in flat elements (B.4, B.5.4.1, F.5)

C_{pov} = coefficient for determining the pull-over strength of a screw (J.5.5.2)

C_s = buckling constant intersection for shear in flat elements (B.4, G.2, G.3, H.2.1)

C_t = buckling constant intersection for axial compression in curved elements (B.4, B.5.4.5, F.6.2)

C_{tb} = buckling constant intersection for bending compression in curved elements (B.4)

C_w = warping constant (E.3.2, F.2.2.3)

C_{wa}, C_{wb}, C_{w1}, C_{w2}, C_{w3} =
coefficients used to determine web crippling strength (J.8.1)

C_1 = coefficient used to determine U (F.2.2.3)

C_2 = coefficient used to determine U (F.2.2.3)

D = nominal diameter of the fastener (J.3.2, J.3.5, J.3.6, J.3.7, J.3.10, J.5, J.5.5.1.1, J.5.5.1.2, J.5.5.2, J.5.6.1, J.5.6.2, J.7)

D = diameter of a rod (H.2.3)

D_{br} = buckling constant slope for bending compression in flat elements (B.4, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, F.4.2, F.5)

D_c = buckling constant slope for compression in columns and beam flanges (B.4, B.5.4.4, E.3, F.2.1, F.3.1)

D_h = nominal diameter of the hole (J.4.6, J.4.7, J.5.5.2)

D_n = nominal dead load (1.3.2, 4.1.3, 5.4)

D_p = buckling constant slope for axial compression in flat elements (B.4, B.5.4.1, B.5.4.2, B.5.4.6, F.5)

D_S = depth of a stiffener (B.5.4.3)

D_s = buckling constant slope for shear in flat elements (B.4, G.2, G.3, H.2.1)

D_{ss} = screw slot inside diameter (J.5.5.1.2)

D_t = buckling constant slope for axial compression in curved elements (B.4, B.5.4.5, F.6.2)

D_{tb} = buckling constant slope for bending compression in curved elements (B.4, F.6.2)

D_{ws} = larger of the nominal washer diameter and the screw head diameter, but no greater than $\frac{5}{8}$ in. (16 mm) (J.5.5.2)

E = compressive modulus of elasticity (A.3.1, A.3.2, A.3.3, B.4, B.5.4.1, B.5.4.2, B.5.4.3, B.5.4.4, B.5.4.5, B.5.4.6, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, B.5.6, E.3, E.3.2, E.5, F.2.1, F.2.2.3, F.2.3, F.3.1, F.4.2, F.5, F.5.1, F.5.2, F.6.2, G.2, G.3, H.2.1, J.8.1, 4.2.3.1, 6.3.2.1, 6.3.2.2)

E_m = compressive modulus of elasticity at elevated temperatures (4.2.3.1)

F_b = stress corresponding to the flexural strength (B.5.5, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, F.2.1, F.2.3, F.3.1, F.4.2, F.6.2, F.8, F.8.1.2, F.8.2, F.8.3, H.3.1, H.3.2)

F_{bo} = stress corresponding to the flexural compression strength for an element if no part of the cross section were weld-affected (B.5.5)

F_{bw} = stress corresponding to the flexural compression strength for an element if the entire cross section were weld-affected (B.5.5)

F_c = stress corresponding to the uniform compressive strength (B.5.4, B.5.4.1, B.5.4.2, B.5.4.3, B.5.4.4, B.5.4.5, B.5.4.6, E.3, E.4.2, F.8.3, H.3.1, H.3.2)

F_{ci} = local buckling stress of element *i* computed per Section B.5.4.1 through B.5.4.5 (E.4.1)

F_{co} = stress corresponding to the uniform compression strength for an element if no part of the cross section were weld-affected (B.5.4)

F_{cw} = stress corresponding to the uniform compression strength for an element if the entire cross section were weld-affected (B.5.4)

F_{cy} = compressive yield strength (A.3.2, A.3.3, B.4, B.5.4.1, B.5.4.2, B.5.4.3, B.5.4.4, B.5.4.5, B.5.4.6, B.5.5.1, B.5.5.2, B.5.5.3, B.5.5.4, E.3, E.4.1, F.4.1, F.5, F.6.1, F.7, F.8.3, J.8.1)

F_{cyw} = compressive yield strength of weld-affected zones (A.3.2)

F_e = elastic buckling stress (B.5.4.6, B.5.5.4, B.5.6, E.3.2, E.5, F.2.3, L.3)

F_{ex} = elastic buckling stress for buckling about the *x*-axis (E.3.2)

F_{ey} = elastic buckling stress for buckling about the *y*-axis (E.3.2, F.2.2.3)

F_{ez} = elastic buckling stress for torsional buckling (E.3.2, F.2.2.3)

F_m = mean value of the fabrication factor (1.3.2)

F_n = shear strength of an A 325 bolt (J.3.8.4)

F_s = shear stress corresponding to the shear strength (G.1, G.2, G.3, H.2.1, H.2.2, H.3.1, H.3.2)

F_{so} = shear stress corresponding to the unwelded shear strength (G.1)

F_{ST} = stress corresponding to the uniform compressive strength of an element supported on both edges (B.5.4.3)

F_{su} = shear ultimate strength (A.3.2, A.3.5, A.3.6, J.3.6, J.4.6, J.5.6.3, J.6.2, J.6.3)

F_{suw} = shear ultimate strength of weld-affected zones (A.3.2, G.1, J.2.1.3)

F_{sw} = shear stress corresponding to the welded shear strength (G.1, J.2.2.2, J.2.3.2)

F_{sy} = shear yield strength (A.3.1, B.4, G.2, G.3, H.2.1, H.2.3, J.6.2, J.6.3)

F_t = tensile stress corresponding to the flexural tensile strength (F.8.1.1, F.8.3)

F_{tu} = tensile ultimate strength (A.3.2, A.3.3, A.3.5, D.2, F.4.1, F.6.1, F.7, F.8.1.1, F.8.1.2, J.3.5, J.3.7, J.4.7, J.5.5.1.2, J.5.5.3, J.5.6.1, J.6.3, J.7)

F_{tum} = tensile ultimate strength at elevated temperatures (4.2.3.1)

F_{tuw} = tensile ultimate strength of weld-affected zones (A.3.2, D.2, F.8.1.1, F.8.1.2, J.2.1.3)

F_{tu1} = tensile ultimate strength of the part in contact with the screw head or washer (J.5.5.2)

F_{tu2} = tensile ultimate strength of member not in contact with the screw head (J.5.5.1.1, J.5.6.2)

F_{ty} = tensile yield strength (A.3.1, A.3.2, A.3.3, D.2, F.4.1, F.6.1, F.7, F.8.1.1, F.8.1.2, J.6.3, 1.4)

F_{tym} = tensile yield strength at elevated temperatures (4.2.3.1)

F_{tyw} = tensile yield strength of weld-affected zones (A.3.2, D.2, F.8.1.1, F.8.1.2)

F_{ty1} = tensile yield strength of the part in contact with the screw head (J.5.5.2)

F_{ty2} = tensile yield strength of member not in contact with the screw head (J.5.5.1.1)

F_{UT} = stress corresponding to the uniform compressive strength of an element supported on one edge only (B.5.4.3)

G = shear modulus of elasticity (A.3.1, E.3.2, F.2.2.3)

G_f = the grip of a bolt (J.3.10)

$H = 1 - \dfrac{x_0^2 + y_0^2}{r_0^2}$ (E.3.2)

I_{cy} = moment of inertia of the compression flange about the *y*-axis (F.1.1.2, F.2.2.3)

I_f = moment of inertia of the flange group about the cross section's neutral axis. The flange group consists of the flat elements in uniform compression or uniform tension and their edge or intermediate stiffeners (F.8.3)

I_L = moment of inertia of the longitudinal stiffener about the web of the beam (B.5.5.3)

I_o = moment of inertia of a section comprising the stiffener and one half of the width of the adjacent sub-elements and the transition corners between them taken about the centroidal axis of the section parallel to the stiffened element (B.5.4.4)

I_s = moment of inertia of the transverse stiffener (G.2)

I_w = moment of inertia of the web group about the cross section's neutral axis. The web group consists of the flat elements in flexure and their intermediate stiffeners. (F.8.3)

I_w = moment of inertia about the major principal axis (F.5.2)

I_x = moment of inertia about the *x*-axis (E.3.2, F.2.2.3)

I_y = moment of inertia about the y-axis (E.3.2, F.1.1.2, F.2.2.1, F.2.2.2, F.2.2.3, F.3.1, 6.3.2.1)

I_z = moment of inertia about the minor principal axis (F.5.2)

J = torsion constant (E.3.2, F.2.2.1, F.2.2.2, F.2.2.3, F.3.1, H.2.1)

K = statistical coefficient based on the number of tests n (1.3.1)

K_s = a coefficient used to determine the pull-out strength of a screw (J.5.5.1.1)

L = member length (E.2, E.3, E.3.1, E.3.2, E.5, E.6.1, F.2.2.3, F.9.1, 6.1, 6.2.2, 6.3.2.1, 6.3.2.2)

L_b = length of a beam between brace points or between a brace point and a cantilever's free end (F.2.1, F.2.2.1, F.2.2.3, F.2.3, F.3.1, F.4.2, F.5.1, F.5.2, 6.1, 6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2, 6.3.2.1, 6.3.2.2, 6.4)

L_C = length of the connection in the direction of load, measured from the center of fasteners or the end of welds (D.3.2)

L_e = length of full thread engagement of a screw in a hole or screw slot not including tapping or drilling point (J.5.5.1.1, J.5.5.1.2)

L_n = nominal live load (1.3.2, 4.1.3, 5.4)

L_s = length of tube between circumferential stiffeners, or overall length if no circumferential stiffeners are present (H.2.1)

L_v = length of tube from maximum to zero shear force (G.3)

L_{we} = effective length of a weld (J.2.1.2, J.2.2.1, J.2.2.2)

L_x = unbraced length for buckling about the x-axis (E.3.2)

L_y = unbraced length for buckling about the y-axis (E.3.2)

L_z = unbraced length for twisting (E.3.2, F.2.2.3)

M = bending moment (J.8.3)

M_A = absolute value of the moment at the quarter point of the unbraced segment (F.1.1.1)

M_B = absolute value of the moment at the midpoint of the unbraced segment (F.1.1.1)

M_C = absolute value of the moment at the three-quarter point of the unbraced segment (F.1.1.1)

M_c = design or allowable flexural strength determined in accordance with Chapter F (H.1, J.8.3)

M_e = elastic lateral-torsional buckling moment (F.2.2.3, F.5, F.5.1, F.5.2)

M_i = bending strength of member of intermediate thickness t_i (1.4.2)

M_m = mean value of the material factor (1.3.2)

M_{max} = absolute value of the maximum moment in the unbraced segment (F.1.1.1, F.1.1.2)

M_n = nominal strength moment (F.1, F.2.1, F.2.3, F.3.1, F.4.1, F.4.2, F.5, F.5.1, F.5.2, F.6.1, F.6.2, F.7, F.8, F.8.3, F.9.2)

M_{nc} = nominal strength moment for compression (F.8.3)

M_{no} = lateral-torsional buckling strength if no part of the cross section were weld-affected (F.9.2)

M_{nt} = nominal strength moment for tension (F.8.3)

M_{nw} = lateral-torsional buckling strength if the entire cross section were weld-affected (F.9.2)

M_r = required flexural strength using LRFD or ASD load combinations (H.1, 6.3.1.1, 6.3.1.2, 6.3.2.1, 6.3.2.2, 6.4)

M_{rb} = required bracing flexural strength using LRFD or ASD load combinations (6.3.2.1)

M_y = yield moment about the axis of bending (F.5)

M_1 = bending strength of member of thinnest material (1.4.2)

M_2 = bending strength of member of thickest material (1.4.2)

N = length of the bearing at the concentrated force (J.8.1)

N = number of cycles to failure (3.2, 3.3)

N_S = number of stress ranges in the spectrum (3.3)

N_s = number of slip planes (J.3.8.5)

P = force (J.8.3)

P_c = design or allowable axial tensile strength determined in accordance with Chapter D, compressive strength determined in accordance with Chapter E, or concentrated force determined in accordance with Section J.8.1 (H.1, J.8.3)

P_n = nominal strength axial force (D.1, D.2, E.1, E.3, E.4.1, E.4.2, E.5, E.6.2)

P_{no} = nominal member buckling strength if no part of the cross section were weld-affected (E.6.2)

P_{nw} = nominal member buckling strength if the entire cross section were weld-affected (E.6.2)

P_r = required axial force using LRFD or ASD load combinations (C.2, H.1, 6.2.1, 6.2.2, 6.4)

P_{rb} = required bracing strength (6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2)

P_y = axial yield strength (C.2)

R = outside radius of a tube (H.2.1)

R = transition radius of a fatigue detail (3.1)

R_a = required strength for ASD (B.3.2.2)

R_b = radius of curved elements taken at the mid-thickness of the element (B.5.2, B.5.4.5, B.5.6, E.6.1, F.6.2, F.9.1, G.3, H.2.1)

R_i = inside bend radius at the juncture of the flange and web; for extruded shapes, $R_i = 0$ (J.8.1)

R_n = nominal strength (B.3.2.1, B.3.2.2, J.2.1.3, J.2.2.2, J.2.3.2, J.2.4, J.3.5, J.3.6, J.3.7, J.3.8.4, J.3.8.5, J.4.6, J.4.7, J.5.5, J.5.5.1.1, J.5.5.1.2, J.5.5.2, J.5.5.3, J.5.6, J.5.6.1, J.5.6.2, J.5.6.3, J.6.1, J.6.2, J.6.3, J.6.4, J.7, J.8.1)

R_S = the ratio of minimum stress to maximum stress for fatigue design (3.1)

R_u = required strength for LRFD (B.3.2.1)

S = section modulus (F.4.1, F.4.2, F.6.1, F.6.2, F.7)

S_c = section modulus on the compression side of the neutral axis (F.2.1, F.2.2.1, F.2.2.2, F.2.2.3, F.2.3, F.3.1, F.5, F.5.1, F.8)

$S_e = 1.28\sqrt{E/F_{cy}}$ (B.5.4.3)

S_n = nominal snow load (4.1.3)

S_{ra} = applied stress range, the algebraic difference between the minimum and maximum calculated stress (3.2)

S_{rd} = allowable stress range (3.2, 3.3)

S_{re} = equivalent stress range (3.3)

S_{ri} = ith stress range in the spectrum (3.3)

S_t = section modulus on the tension side of the neutral axis (F.8)

S_w = size of a weld (J.2.1.2, J.2.2.1, J.2.2.2)

S_x = standard deviation of the test results (1.3.1)

S_1 = slenderness ratio at the intersection of the equations for yielding and inelastic buckling

S_2 = slenderness ratio at the intersection of the equations for inelastic buckling and elastic buckling

T = temperature (A.3.1.1)

T = nominal forces and deformations due to the design-basis fire defined in Section 4.2.1 (4.1.3)

T_b = minimum fastener tension (J.3.8.5)

T_n = nominal torsional strength (H.2, H.2.1, H.2.2, H.2.3)

T_{uw} = tensile strength of the stud in Table J.2.2 or Table J.2.2M (J.2.4)

T_1 = temperature (A.3.1.1)

T_2 = temperature (A.3.1.1)

U = coefficient used to determine M_e (F.2.2.3)

V = shear force on the web at the transverse stiffener (G.2)

V_F = coefficient of variation of the fabrication factor (1.3.2)

V_M = coefficient of variation of the material factor (1.3.2)

V_n = nominal shear strength (G.1, G.2, G.3)

V_P = coefficient of variation of the ratio of the observed failure loads divided by the average value of all the observed failure loads (1.3.2)

V_Q = coefficient of variation of the loads (1.3.2)

X_a = strength which 99% of the material is expected to exceed with a confidence of 95% (1.3.1)

X_i = result of the ith test (1.3.2)

X_m = mean of the test results (1.3.1, 1.3.2)

a = fraction of the length of a member (F.2.2.3)

a = fatigue detail dimension parallel to the direction of stress (3.1)

a_1 = shorter dimension of rectangular panel (G.2)

a_2 = longer dimension of rectangular panel (G.2)

b = element width (B.5.1, B.5.3, B.5.4, B.5.4.1, B.5.4.2, B.5.4.3, B.5.4.4, B.5.5, B.5.5.1, B.5.5.2, B.5.5.3, B.5.6, F.5, F.5.1, F.5.2, G.1, G.2, J.1.3, L.3)

b = fatigue detail dimension normal to the direction of stress and the surface of the base metal (3.1)

b_e = element's effective width for determining deflections (L.3)

b_s = stiffener width (6.3.2.1)

c = distance from the neutral axis to the extreme fiber (F.9.2)

c_c = distance from neutral axis to the element extreme fiber with the greatest compression stress (B.5.5.1)

c_{cf} = distance from the centerline of the compression flange to the cross section's neutral axis (F.8.3)

c_{cs} = distance from the cross section's neutral axis to the extreme fiber of compression flange stiffeners (F.8.3)

c_{cw} = distance from the web group's extreme compression fiber to the cross section's neutral axis (F.8.3)

c_o = distance from neutral axis to other extreme fiber of the element (see c_c) (B.5.5.1)

c_{tf} = distance from the extreme tension fiber to the cross section's neutral axis (F.8.3)

c_{tw} = distance from the web group's extreme tension fiber to the cross section's neutral axis (F.8.3)

d = full depth of the section (F.2.2.1, F.2.2.2, F.4.2, G.2, J.8.1, J.9.1)

d_e = distance from the center of the fastener to the edge of the part in the direction of force (J.3.7, J.4.7, J.5.6.1, J.7)

d_f = the distance between the flange centroids; for T-shapes d_f is the distance between the flange centroid and the tip of the stem. (F.2.2.3)

d_s = stiffener's flat width (B.5.4.3)

d_1 = distance from the neutral axis to the compression flange (B.5.5.3)

e = base for natural logarithms = 2.71828 . . . (1.3.2)

f = compressive stress at the toe of the flange (B.5.5.3)

f_a = maximum compressive stress in the element from the service load combinations (L.3)

f_b = compressive stress due to flexure (H.3.1, H.3.2)

f_c = compressive stress due to axial compression (H.3.1, H.3.2)

f_s = shear stress due to shear and torsion (H.3.1, H.3.2)

g = transverse center-to-center spacing (gage) between fastener gage lines (D.3.1, J.1.3)

g_0 = distance from the shear center to the point of application of the load; g_0 is positive when the load acts away from the shear center and negative when the load acts towards the shear center. If there is no transverse load (pure moment cases) $g_0 = 0$. (F.2.2.3)

h_o = distance between flange centroids (6.3.1.1, 6.3.1.2, 6.3.2.1, 6.3.2.2)

h_{sc} = hole factor for slip-critical bolted connections (J.3.8.5)

$j = \frac{1}{2I_x}\left(\int_A y^3\,dA + \int_A yx^2\,dA\right) - y_o$ (F.2.2.3)

k = effective length factor for buckling (C.3, E.2, E.3, E.3.1, E.3.2, E.5, J.1.3, 6.1, 6.2.2)

k_t = tension coefficient (A.3.1.3, D.2, F.4.1, F.6.1, F.7, F.8.1.1, F.8.1.2)

k_x = effective length factor for flexural buckling about the x-axis (E.3.2)

k_y = effective length factor for flexural buckling about the y-axis (E.3.2)

k_y = effective length factor for the compression flange about the y-axis (F.2.2.3)

k_z = effective length factor for torsional buckling (E.3.2, F.2.2.3)

k_1 = coefficient for determining the S_2 slenderness limit for elements with postbuckling strength (B.4, B.5.4.1, B.5.4.2, B.5.4.6, B.5.5.1, B.5.5.3, B.5.5.4)
k_2 = coefficient for determining postbuckling strength (B.4, B.5.4.1, B.5.4.2, B.5.4.6, B.5.5.1, B.5.5.3, B.5.5.4)
m = coefficient for elements in flexure and supported on both edges (B.5.5.1)
m = coefficient used to determine the allowable stress range for fatigue (3.2, 3.3)
n = number of threads/in. (mm) (J.3.5, J.3.6, J.5.5.1.1)
n = number of nodal braced points in the span (6.3.2.1, 6.3.2.2)
n = number of tests (1.3.1, 1.3.2)
q = design pressure load for roofing and siding (1.4)
r = radius of gyration (E.2, E.3, E.3.1, E.3.2, E.5)
r_o = polar radius of gyration of the cross section about the shear center (E.3.2, F.2.2.3)
r_s = stiffener's radius of gyration about the stiffened element's mid-thickness (B.5.4.3)
r_x = radius of gyration about the x-axis (E.3.2, F.2.2.3)
r_y = radius of gyration about the y-axis (E.3.2, F.2.1, F.2.2.3)
r_{ye} = effective radius of gyration about the y-axis for lateral-torsional buckling (F.2.1, F.2.2.1, F.2.2.2, F.2.2.3, F.2.3)
r_z = radius of gyration about the minor principal axis (F.5.2)
s = transverse stiffener spacing. For a stiffener composed of a pair of members, one on each side of the web, the stiffener spacing s is the clear distance between the pairs of stiffeners. For a stiffener composed of a member on only one side of the web, the stiffener spacing s is the distance between fastener lines or other connecting lines. (B.5.5.3, G.2)
s = longitudinal center-to-center spacing (pitch) of any two consecutive holes (D.3.1, J.1.3)
t = element thickness (B.5.4, B.5.4.1, B.5.4.2, B.5.4.3, B.5.4.4, B.5.4.5, B.5.5, B.5.5.1, B.5.5.2, B.5.5.3, B.5.6, E.6.1, F.4.2, F.5, F.5.1, F.5.2, F.6.2, F.9.1, G.1, G.2, G.3, H.2.1, J.1.3, J.3.7, J.4.7, J.5.6.1, J.7, J.8.1,)
t = time (A.3.1.1)
t_{avg} = average thickness of a tapered thickness element (B.5.3)
t_i = thickness of intermediate thickness material (1.4.2)
$t_{\max}$ = maximum thickness of a tapered thickness element (B.5.3)
$t_{\max}$ = thickness of thickest material tested (1.4.2)
$t_{\min}$ = minimum thickness of a tapered thickness element (B.5.3)
$t_{\min}$ = thickness of thinnest material tested (1.4.2)
t_s = beam web stiffener thickness (6.3.2.1)
t_w = beam web thickness (6.3.2.1, 6.3.2.2)
t_1 = nominal thickness of the part in contact with the screw head or washer (J.5.5.2, J.5.6.2)
t_1 = time corresponding to temperature T_1 (A.3.1.1)
t_2 = nominal thickness of the part not in contact with the screw head or washer (J.5.6.2)
t_2 = time corresponding to temperature T_2 (A.3.1.1)
$\overline{x}$ = eccentricity of the connection in the x-axis direction (D.3.2)
x_o = the shear center's x-coordinate (E.3.2, F.2.2.3)
$\overline{y}$ = eccentricity of the connection in the y-axis direction (D.3.2)
y_o = the shear center's y-coordinate (E.3.2, F.2.2.3)
z_o = coordinate along the z-axis of the shear center with respect to the centroid (F.5.2)
α = factor used to determine reduced flexural stiffness (C.2)
α = ratio of nominal dead load to nominal live load (1.3.2)
α = coefficient of thermal expansion (A.3.1)
α_i = number of cycles in the spectrum of the ith stress range divided by the total number of cycles (3.3)
α_s = coefficient for a longitudinal stiffener (B.5.5.3)
β_{br} = required bracing stiffness (6.2.1, 6.2.2, 6.3.1.1, 6.3.1.2)
β_o = target reliability index (1.3.2)
β_{sec} = web distortional stiffness (6.3.2.1, 6.3.2.2)
β_{Tb} = required bracing torsional stiffness (6.3.2.1)
β_w = section property for unequal leg angles (F.5.2)
γ = density (A.3.1)
$\delta = \frac{(t_{\max} - t_{\min})}{t_{\min}}$ = a measure of taper in tapered thickness elements (B.5.3)
κ = metric conversion factor (Table B.4.1, Table B.4.2)
ν = Poisson's ratio (A.3.1)
ϕ = resistance factor (B.3.2.1, D.1, E.1, F.1, G.1, H.2, H.3.1, H.3.2, J.2, J.3.5, J.3.6, J.3.7, J.3.8.4, J.3.8.5, J.4.6, J.4.7, J.5.5, J.5.6, J.6.2, J.6.3, J.7, J.8.1, 1.3.2, 6.1)
Ω = safety factor (B.3.2.2, D.1, E.1, F.1, G.1, H.2, H.3.1, H.3.2, J.2, J.3.5, J.3.6, J.3.7, J.3.8.4, J.3.8.5, J.4.6, J.4.7, J.5.5, J.5.6, J.6.2, J.6.3, J.7, J.8.1, 1.3.2, 6.1)
θ = angle between a stiffener and the stiffened element (B.5.4.3)
θ = angle between the plane of web and the plane of the bearing surface ($\theta \leq 90°$) (J.8.1)
ρ_{ST} = stiffener effectiveness ratio (B.5.4.3, B.5.6)
$\lambda_{eq} = \pi\sqrt{\frac{E}{F_e}}$ = equivalent slenderness ratio for alternate determination of compressive strength for flexure or axial compression (B.5.4.6, B.5.5.4)
λ_s = slenderness ratio of an element with an intermediate stiffener (B.5.4.4, B.5.6)
λ_t = slenderness ratio for round or oval tubes in shear or torsion (G.3, H.2.1)
τ_b = parameter for reduced flexural stiffness (C.2)
μ = mean slip coefficient (J.3.8.5)

Glossary

allowable strength: nominal strength divided by the safety factor, R_n/Ω.

allowable stress: allowable strength divided by the appropriate section property, such as section modulus or cross section area.

aluminum: aluminum or an aluminum alloy.

analysis: the rational determination of the effects of loads on and the strength of structures, members, and connections based on appropriate theory, relevant test data, and sound engineering judgment.

applicable building code: the building code under which the structure is designed.

ASD (Allowable Strength Design): the method of proportioning structural components such that the allowable strength equals or exceeds the required strength of the component under the action of the ASD load combinations.

ASD load combination: the load combination in the applicable building code intended for allowable strength design.

available strength: for LRFD, design strength; for ASD, allowable strength.

beam: a structural member that has the primary function of resisting bending moments.

bearing-type connection: a bolted connection where shear forces are transmitted by the bolt bearing against the connection elements.

blind rivet: a rivet that can be installed with access to only one side of the parts being joined.

block shear rupture: in a connection, the limit state of tension fracture or yielding along one path and shear yielding or fracture along another path.

bolt: a headed and externally threaded mechanical device designed for insertion through holes in assembled parts to mate with a nut and normally intended to be tightened or released by turning that nut.

bridge-type structure: a structure not addressed by building codes and designed for highway, pedestrian, or rail traffic.

buckling: the limit state of a sudden change in the geometry of a structure or any of its elements under a critical loading condition.

building-type structure: a structure of the type addressed by a building code.

camber: curvature fabricated into a beam or truss so as to compensate for deflection induced by loads.

closed shape: a hollow shape that resists lateral-torsional buckling primarily by torsional resistance rather than warping resistance, that is, for which C_w is much less than $0.038JL_b^2$. See Section F.3.

column: a structural member that has the primary function of resisting a compressive axial force.

contract documents: documents that define the responsibilities of the parties that design, fabricate, or erect the structure.

design load: the applied load determined in accordance with either LRFD load combinations or ASD load combinations, whichever is applicable.

design strength: the resistance factor multiplied by the nominal strength, ϕR_n.

design stress: the design strength divided by the appropriate section property, such as section modulus or cross section area.

effective length: the length of an otherwise identical column with the same strength when analyzed with pinned end conditions.

effective length factor: ratio between the effective length and the unbraced length of the member.

effective net area: net area modified to account for the effect of shear lag.

elastic analysis: structural analysis based on the assumption that the structure returns to its original geometry on removal of the load.

element: a component of a shape's cross section. Elements are connected to other elements only along their longitudinal edges. Elements addressed by the *Specification* include flat elements, described by their width b and thickness t, and curved elements, described by their mid-thickness radius R_b and thickness t. An Aluminum Association standard I beam, for example, consists of five flat elements: a web element and two elements in each flange.

factored load: the product of a load factor and the nominal load.

fastener: bolts, rivets, screws, or other connection devices.

fatigue: the limit state of crack initiation and growth resulting from repeated application of loads.

filler metal: metal to be added in making a welded joint.

fillet weld: weld of generally triangular cross section made between intersecting surfaces of elements.

flexural buckling: a buckling mode in which a compression member deflects laterally without twist or change in cross-sectional shape.

flexural-torsional buckling: a buckling mode in which a compression member bends and twists simultaneously without change in cross-sectional shape.

gage: transverse center-to-center spacing of fasteners.

gauge: a term previously used in referring to the thickness of a wrought product. Thickness is preferred in dimension description.

geometric axis: axis parallel to a web, flange, or angle leg.

grip: thickness of material through which a fastener passes.

lateral-torsional buckling: the buckling mode of a flexural member involving deflection normal to the plane of bending occurring simultaneously with twist about the shear center of the cross-section.

limit state: a condition in which a structure or component becomes unfit for service and is judged either to be no longer useful for its intended function (serviceability limit state) or to have reached its ultimate load-carrying capacity (strength limit state).

load effect: forces, stresses, and deformations produced in a structural component by the applied loads.

load factor: a factor that accounts for deviations of the nominal load from the actual load, for uncertainties in the analysis that transforms the load into a load effect and for the probability that more than one extreme load will occur simultaneously.

local buckling: the limit state of buckling of a compression element within a cross section.

lockbolt: a two piece fastener consisting of a pin (bolt) and collar. The softer, smooth bore collar is mechanically swaged (reduced or tapered by squeezing) onto the pin and into either zero pitch, annular lock grooves or special thread form grooves in a tension-tension installation method. Hydraulic or pneumatic installation tools provide the tension and swaging action.

longitudinal centroidal axis: axis through the centroid of a member along its length

LRFD (*Load and Resistance Factor Design*): a method of proportioning structural components such that the design strength equals or exceeds the required strength of the component under the action of the LRFD load combinations.

LRFD load combination: a load combination in the applicable building code intended for strength design (load and resistance factor design).

member: an individual, discrete component of a larger structure, such as a beam or column.

member buckling: flexural, torsional, or flexural-torsional buckling of the overall member.

net area: gross area reduced to account for removed material.

nominal dimension: designated or theoretical dimension, as in the tables of section properties.

nominal load: magnitude of the load specified by the applicable building code.

nominal strength: strength of a structure or component (without the resistance factor or safety factor applied) available to resist load effects, as determined in accordance with this *Specification.*

pitch: longitudinal center-to-center spacing of fasteners; center-to-center spacing of bolt threads along the axis of a bolt.

post-buckling strength: the load or force that can be carried by an element, member, or frame after initial elastic buckling has occurred.

pull-out: the tensile load required to pull a screw out of a threaded part.

pull-over: the tensile load required to pull a part over the head of a screw.

resistance factor: a factor that accounts for unavoidable deviations of the actual strength from the nominal strength and for the manner and consequences of failure.

rivet: a headed and unthreaded mechanical device used to assemble two or more components by an applied force which deforms the plain rivet end to develop a completed mechanical joint.

rod: a solid wrought product that is long in relation to its circular cross section, which is not less than 0.375 in. diameter.

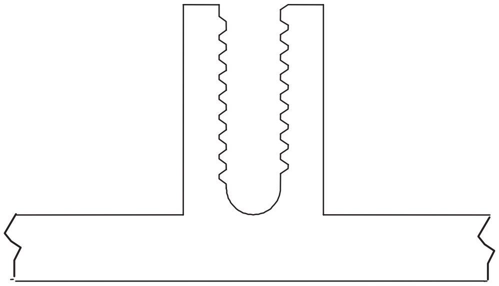


Figure GL.1
TRANSVERSE CROSS SECTION
OF A SCREW CHASE

safety factor: a factor that accounts for deviations of the actual strength from the nominal strength, deviations of the actual load from the nominal load, uncertainties in the analysis that transforms the load into a load effect, and for the manner and consequences of failure.

screw: a headed and externally threaded fastener held in place by threading into one of the connected parts.

screw chase: a groove parallel to the longitudinal axis of an extrusion, intended to retain a screw whose axis is perpendicular to the longitudinal axis of the extrusion. (See Figure GL.1).

screw slot: a semi-hollow in an extrusion intended to retain a screw parallel to the axis of the extrusion. (See Figure GL.2).

self-drilling screw: a screw that drills and taps its own hole as it is being driven.

service load combination: load combinations under which serviceability limit states are evaluated.

slip-critical connection: a bolted connection designed to resist movement by friction on the faying surface of the connection under the clamping forces of the bolts.

stiffener: a structural element attached or integral to a member to distribute load, transfer shear, or prevent buckling.

structural component: member, connector, connecting element or assemblage.

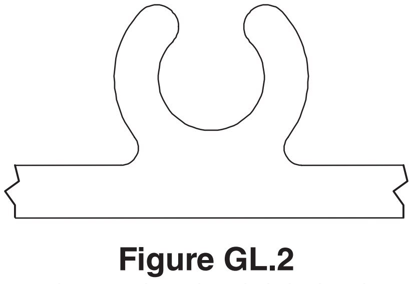


Figure GL.2
TRANSVERSE CROSS SECTION
OF A SCREW SLOT

structure: an object, including but not limited to buildings, walls, fences, towers, bridges, railings, signs, and luminaires, designed to support loads.

tapping screw: a screw that threads a preformed hole as it is being driven.

thread cutting screw: a tapping screw that is installed into a preformed hole, with internal mating threads formed as a result of cutting out the material being tapped to form the relief area of the threaded shank.

thread forming screw: a tapping screw that is installed into a preformed hole, with internal mating threads formed as a result of cold flow of the material being tapped into the relief area of the threaded shank.

torsional buckling: a buckling mode in which a compression member twists about its shear center axis.

unbraced length: the length of a member between brace points or between a brace point and a cantilever's free end, measured between the longitudinal centroidal axes of the bracing members. For columns, brace points are points at which lateral translation is restrained for flexural buckling or twisting is restrained for torsional buckling. For beams, brace points are points at which the compression flange is restrained against lateral deflection or the cross section is restrained against twisting.

weld-affected zone: metal within 1in. (25 mm) of the centerline of a weld.

Chapter A General Provisions

A.1 Scope

The *Specification for Aluminum Structures,* hereafter referred to as the *Specification,* applies to the design of aluminum load-carrying structures, members, and connections.

This *Specification* includes the symbols, glossary, Chapters A through M, and Appendices 1 through 6.

The provisions of this *Specification,* or a more rigorous analysis, shall be used for all cases addressed by this *Specification.* Appropriate analysis shall be used for cases not addressed by this *Specification.*

A.2 Referenced Documents

The following documents are referenced in this *Specification:*

Aluminum Association
Aluminum Standards and Data 2009
Aluminum Standards and Data 2009 Metric SI
Standards for Aluminum Sand and Permanent Mold Castings (2008)

American Association of State Highway and Traffic Officials (AASHTO)
Guide Specifications for Design of Pedestrian Bridges (1997)
Standard Specifications for Highway Bridges (2002)
Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals (2009)

American Society of Civil Engineers (ASCE)
ASCE/SEI 7-05 *Minimum Design Loads for Buildings and Other Structures*

American Society of Mechanical Engineers (ASME)
ASME B18.6.4-1999 *Thread Forming and Thread Cutting Tapping Screws and Metallic Drive Screws, Inch Series*
ASME B46.1-2002 *Surface Texture, Surface Roughness, Waviness and Lay*

American Welding Society (AWS)
AWS A.5.10/A5.10M:1999(R2007) *Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods*
AWS D1.2/D1.2M:2008 *Structural Welding Code—Aluminum*

ASTM International (ASTM)
A 123/A 123M-09 *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*
A 153/A 153M-09 *Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware*
A 193/A 193M-09 *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications*
A 194/A 194M-09 *Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both*
A 320/A 320M-08 *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for Low-Temperature Service*
A 325-09a *Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength*
A 325M-09 *Standard Specification for Structural Bolts, Steel, Heat Treated 830 MPa Minimum Tensile Strength* [*Metric*]
A 563-07a *Standard Specification for Carbon and Alloy Steel Nuts*
A 563M-07 *Standard Specification for Carbon and Alloy Steel Nuts* [*Metric*]
A 641/A 641M-09a *Standard Specification for Zinc-Coated (Galvanized) Carbon Steel Wire*
B 26/B 26M-09 *Standard Specification for Aluminum-Alloy Sand Castings*
B 108/B 108M-08 *Standard Specification for Aluminum-Alloy Permanent Mold Castings*
B 209-07 *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate*
B 209M-07 *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate* [*Metric*]
B 210-04 *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes*
B 210M-05 *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes* [*Metric*]
B 211-03 *Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire*
B 211M-03 *Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire* [*Metric*]
B 221-08 *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes*
B 221M-07 *Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes* [*Metric*]
B 241/B 241M-02 *Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube*
B 247-09 *Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings*
B 247M-09 *Standard Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings* [*Metric*]
B 308/B 308M-02 *Standard Specification for Aluminum-Alloy 6061-T6 Standard Structural Profiles*
B 316/B 316M-02 *Standard Specification for Aluminum and Aluminum-Alloy Rivet and Cold-Heading Wire and Rods*
B 429/B 429M-06 *Standard Specification for Aluminum-Alloy Extruded Structural Pipe and Tube*

B 456-03 *Standard Specification for Electrodeposited Coatings of Copper Plus Nickel Plus Chromium and Nickel Plus Chromium*

B 557-06 *Standard Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products*

B 557M-07e1 *Standard Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products* [*Metric*]

B 632/B 632M-08 *Standard Specification for Aluminum-Alloy Rolled Tread Plate*

B 695-04 *Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel*

B 928/B 928M-09 *Standard Specification for High Magnesium Aluminum-Alloy Sheet and Plate for Marine Service and Similar Environments*

E 119-09c *Standard Test Methods for Fire Tests of Building Construction and Materials*

E 330-02 *Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference*

E 1592-05 *Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference*

F 436-09 *Standard Specification for Hardened Steel Washers*

F 436M-09 *Standard Specification for Hardened Steel Washers* [*Metric*]

F 467-08e1 *Standard Specification for Nonferrous Nuts for General Use*

F 467M-06ae2 *Standard Specification for Nonferrous Nuts for General Use* [*Metric*]

F 468-06e1 *Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use*

F 468M-06e1 *Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use* [*Metric*]

F 593-02(2008) *Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs*

F 594-08 *Standard Specification for Stainless Steel Nuts*

F 606-09 *Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets*

F 606M-07e1 *Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, and Rivets* [*Metric*]

Federal Specification

TT-P-645B(1) *Primer, Paint, Zinc-Molybdate, Alkyd Type*

Research Council on Structural Connections (RCSC)

Specification for Structural Joints Using ASTM A325 or A490 Bolts, 2004

A.3 Material

A.3.1 General Properties

The properties listed in Table A.3.1 shall be used unless more precise values are specified.

Table A.3.1
GENERAL PROPERTIES

Property	Symbol	Value
Poisson's ratio	ν	0.33
Shear modulus of elasticity	G	$3E/8$
Coefficient of thermal expansion	α	$13 \times 10^{-6}/°F = 23 \times 10^{-6}/°C$
Density	γ	$0.10\ lb/in^3 = 2.7 \times 10^3\ kg/m^3$
Shear yield strength	F_{sy}	$0.6\ F_{ty}$

A.3.1.1 Mechanical Properties

Except as noted in Section A.3.1.2, the mechanical properties given in Sections A.3.2 through A.3.6 apply to material held at temperatures of 200°F (93°C) or less for any period of time and for the alloys and tempers listed in Table A.3.2 held at the temperatures listed in Table A.3.2 for cumulative periods of time no greater than the times listed in Table A.3.2. When alloys not addressed in Table A.3.2 are heated above 200°F or alloy-tempers addressed in Table A.3.2 are heated beyond the time-temperature limits of Table A.3.2, mechanical properties shall be reduced to the mechanical properties after heating.

Table A.3.2
TIME-TEMPERATURE LIMITS FOR T5 AND T6 TEMPERS OF 6005, 6061, AND 6063

Temperature		
°F	°C	Time
450	230	5 min
425	220	15 min
400	205	30 min
375	190	2 hr
350	175	10 hr
325	165	100 hr
300	150	1,000 hr
212	100	100,000 hr

Interpolate time (t) for other temperatures (T) using

$$\log t = \log t_2 + \frac{\log(T_2/T)}{\log(T_2/T_1)} \log (t_1/t_2) \qquad \text{(A.3-1)}$$

where

T_1 = next lower temperature in Table A.3.2 than T
T_2 = next higher temperature in Table A.3.2 than T
t_1 = time corresponding to T_1
t_2 = time corresponding to T_2

A.3.1.2 Temperature Limits

Alloys 535.0, 5083, 5086, 5154, and 5456 shall not be subjected to temperatures greater than 150°F (66°C), except during fabrication in accordance with Section M.3.

A.3.1.3 Tension Coefficient k_t

The tension coefficient k_t shall be as listed in Table A.3.3.

Table A.3.3
TENSION COEFFICIENT k_t

Alloy and Temper	Unwelded	Weld-Affected Zones
2014-T6, -T651, -T6510, -T6511 Alclad 2014-T6, -T651	1.25	–
6005-T5, 6105-T5	1.25	–
6066-T6, -T6510, -T6511	1.1	–
6070-T6, -T62	1.1	–
all others listed in Table A.3.4 and Table A.3.6	1.0	1.0

A.3.2 Wrought Products

This *Specification* applies to the wrought alloys listed in Tables A.3.4, A.3.8, and A.3.9 and produced to the following ASTM specifications:

B 209 *Aluminum and Aluminum-Alloy Sheet and Plate*
B 209M *Aluminum and Aluminum-Alloy Sheet and Plate* [*Metric*]
B 210 *Aluminum and Aluminum-Alloy Drawn Seamless Tubes*
B 210M *Aluminum and Aluminum-Alloy Drawn Seamless Tubes* [*Metric*]
B 211 *Aluminum and Aluminum-Alloy Bar, Rod, and Wire*
B 211M *Aluminum and Aluminum-Alloy Bar, Rod, and Wire* [*Metric*]
B 221 *Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes*
B 221M *Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes* [*Metric*]
B 241/B 241M *Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube*
B 247 *Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings*
B 247M *Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings* [*Metric*]
B 308/B 308M *Aluminum-Alloy 6061-T6 Standard Structural Profiles*
B 316/B 316M *Aluminum and Aluminum-Alloy Rivet and Cold-Heading Wire and Rods*
B 429/B 429M *Aluminum-Alloy Extruded Structural Pipe and Tube*
B 632/B 632M *Aluminum-Alloy Rolled Tread Plate*
B 928/B 928M *High Magnesium Aluminum-Alloy Sheet and Plate for Marine Service and Similar Environments*

Mechanical properties for unwelded metal shall be as listed in Table A.3.4 or A.3.4M. Mechanical properties for weld-affected zones shall be as listed in Table A.3.5 or A.3.5M.

A.3.3 Castings

This *Specification* applies to cast products listed in Table A.3.6 and produced to the following ASTM specifications:

B 26/B 26M *Aluminum-Alloy Sand Castings*
B 108/B 108M *Aluminum-Alloy Permanent Mold Castings*

Dimensional tolerances shall conform to *Standards for Aluminum Sand and Permanent Mold Castings.*

The purchaser shall require the casting producer to report tensile yield strengths. For sand castings, the purchaser shall require that tensile ultimate and tensile yield strengths of specimens cut from castings shall be at least 75% of the values specified in ASTM B 26.

Radiographic inspection in accordance with ASTM B 26 Grade C or B 108 Grade C criteria is required. The number of castings radiographed and the lot acceptance criteria shall be as listed in Table A.3.7.

Strengths shall be taken from Table A.3.6 or Table A.3.6M. The compressive yield strength F_{cy} of castings shall be taken as the tensile yield strength F_{ty}. The modulus of elasticity E of castings shall be taken as 10,000 ksi (70,000 MPa).

Welded strengths of castings shall be those established in the AWS D1.2 weld procedure qualification test.

A.3.4 Filler Metal for Welding

This *Specification* applies to filler alloys produced to AWS A.5.10/A5.10M and listed in Tables M.9.1 and M.9.2. Mechanical properties for filler metal shall be as listed in Table J.2.1 or Table J.2.1M.

A.3.5 Bolts and Nuts

This *Specification* applies to aluminum fasteners produced to ASTM specifications

F 468 *Nonferrous Bolts, Hex Cap Screws, and Studs for General Use*
F 468M *Nonferrous Bolts, Hex Cap Screws, and Studs for General Use* [*Metric*]

and aluminum nuts produced to ASTM specifications

F 467 *Nonferrous Nuts for General Use*
F 467M *Nonferrous Nuts for General Use* [*Metric*]

Strengths for aluminum bolts shall be as listed in Table A.3.8 or A.3.8M.

A.3.6 Rivets

This *Specification* applies to rivets of material that meets ASTM B 316/B 316M. Strengths for aluminum rivets shall be as listed in Table A.3.9 or Table A.3.9M.

A.3.7 Screws

This *Specification* applies to aluminum tapping screws that meet ASME B18.6.4.

Table A.3.4
MECHANICAL PROPERTIES FOR WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	PRODUCT	THICKNESS in.	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	F_{su} ksi	E ksi
1100	-H12	Sheet, Plate, Drawn Tube,	All	14	11	10	9	10,100
	-H14	Rod & Bar	All	16	14	13	10	10,100
2014	-T6	Sheet	0.040 to 0.249	66	58	59	40	10,900
	-T651	Plate	0.250 to 2.000	67	59	58	40	10,900
	-T6, T6510, T6511	Extrusions	All	60	53	52	35	10,900
	-T6, T651	Rod & Bar, Drawn Tube	All	65	55	53	38	10,900
Alclad 2014	-T6	Sheet	0.025 to 0.039	63	55	56	38	10,800
	-T6	Sheet	0.040 to 0.249	64	57	58	39	10,800
	-T651	Plate	0.250 to 0.499	64	57	56	39	10,800
3003	-H12	Sheet & Plate	0.017 to 2.000	17	12	10	11	10,100
	-H14	Sheet & Plate	0.009 to 1.000	20	17	14	12	10,100
	-H16	Sheet	0.006 to 0.162	24	21	18	14	10,100
	-H18	Sheet	0.006 to 0.128	27	24	20	15	10,100
	-H12	Drawn Tube	All	17	12	11	11	10,100
	-H14	Drawn Tube	All	20	17	16	12	10,100
	-H16	Drawn Tube	All	24	21	19	14	10,100
	-H18	Drawn Tube	All	27	24	21	15	10,100
Alclad 3003	-H12	Sheet & Plate	0.017 to 2.000	16	11	9	10	10,100
	-H14	Sheet & Plate	0.009 to 1.000	19	16	13	12	10,100
	-H16	Sheet	0.006 to 0.162	23	20	17	14	10,100
	-H18	Sheet	0.006 to 0.128	26	23	19	15	10,100
	-H14	Drawn Tube	0.025 to 0.259	19	16	15	12	10,100
	-H18	Drawn Tube	0.010 to 0.500	26	23	20	15	10,100
3004	-H32	Sheet & Plate	0.017 to 2.000	28	21	18	17	10,100
	-H34	Sheet & Plate	0.009 to 1.000	32	25	22	19	10,100
	-H36	Sheet	0.006 to 0.162	35	28	25	20	10,100
	-H38	Sheet	0.006 to 0.128	38	31	29	21	10,100
	-H34	Drawn Tube	0.018 to 0.450	32	25	24	19	10,100
	-H36	Drawn Tube	0.018 to 0.450	35	28	27	20	10,100
Alclad 3004	-H32	Sheet	0.017 to 0.249	27	20	17	16	10,100
	-H34	Sheet	0.009 to 0.249	31	24	21	18	10,100
	-H36	Sheet	0.006 to 0.162	34	27	24	19	10,100
	-H38	Sheet	0.006 to 0.128	37	30	28	21	10,100
	-H131, H241, H341	Sheet	0.024 to 0.050	31	26	22	18	10,100
	-H151, H261, H361	Sheet	0.024 to 0.050	34	30	28	19	10,100
3005	-H25	Sheet	0.013 to 0.050	26	22	20	15	10,100
	-H28	Sheet	0.006 to 0.080	31	27	25	17	10,100
3105	-H25	Sheet	0.013 to 0.080	23	19	17	14	10,100
5005	-H12	Sheet & Plate	0.017 to 2.000	18	14	13	11	10,100
	-H14	Sheet & Plate	0.009 to 1.000	21	17	15	12	10,100
	-H16	Sheet	0.006 to 0.162	24	20	18	14	10,100
	-H32	Sheet & Plate	0.017 to 2.000	17	12	11	11	10,100
	-H34	Sheet & Plate	0.009 to 1.000	20	15	14	12	10,100
	-H36	Sheet	0.006 to 0.162	23	18	16	13	10,100
5050	-H32	Sheet	0.017 to 0.249	22	16	14	14	10,100
	-H34	Sheet	0.009 to 0.249	25	20	18	15	10,100
	-H32	Rod & Bar, Drawn Tube	All	22	16	15	13	10,100
	-H34	Rod & Bar, Drawn Tube	All	25	20	19	15	10,100
5052	-O	Sheet & Plate	0.006 to 3.000	25	9.5	9.5	16	10,200
	-H32	Sheet & Plate, Rod & Bar,	All	31	23	21	19	10,200
	-H34	Drawn Tube	All	34	26	24	20	10,200
	-H36	Sheet	0.006 to 0.162	37	29	26	22	10,200

Table A.3.4
MECHANICAL PROPERTIES FOR WROUGHT ALUMINUM PRODUCTS (Continued)

ALLOY	TEMPER	PRODUCT	THICKNESS in.	F_{tu} ksi	F_{ty} ksi	F_{cy} ksi	F_{su} ksi	E ksi
5083	-O	Extrusions	up thru 5.000	39	16	16	24	10,400
	-H111	Extrusions	up thru 0.500	40	24	21	24	10,400
	-H111	Extrusions	0.501 to 5.000	40	24	21	23	10,400
	-O	Sheet & Plate	0.051 to 1.500	40	18	18	24	10,400
	-H116, H32, H321	Sheet & Plate	0.188 to 1.500	44	31	26	26	10,400
	-H116, H32, H321	Plate	1.501 to 3.000	41	29	24	24	10,400
5086	-O	Extrusions	up thru 5.000	35	14	14	21	10,400
	-H111	Extrusions	up thru 5.000	36	21	18	21	10,400
	-O	Sheet & Plate	0.020 to 2.000	35	14	14	21	10,400
	-H112	Plate	0.025 to 0.499	36	18	17	22	10,400
	-H112	Plate	0.500 to 1.000	35	16	16	21	10,400
	-H112	Plate	1.001 to 2.000	35	14	15	21	10,400
	-H112	Plate	2.001 to 3.000	34	14	15	21	10,400
	-H116	Sheet & Plate	All	40	28	26	24	10,400
	-H32	Sheet & Plate, Drawn Tube	All	40	28	26	24	10,400
	-H34	Sheet & Plate, Drawn Tube	All	44	34	32	26	10,400
5154	-H38	Sheet	0.006 to 0.128	45	35	33	24	10,300
5454	-O	Extrusions	up thru 5.000	31	12	12	19	10,400
	-H111	Extrusions	up thru 0.500	33	19	16	20	10,400
	-H111	Extrusions	0.501 to 5.000	33	19	16	19	10,400
	-H112	Extrusions	up thru 5.000	31	12	13	19	10,400
	-O	Sheet & Plate	0.020 to 3.000	31	12	12	19	10,400
	-H32	Sheet & Plate	0.020 to 2.000	36	26	24	21	10,400
	-H34	Sheet & Plate	0.020 to 1.000	39	29	27	23	10,400
5456	-O	Sheet & Plate	0.051 to 1.500	42	19	19	26	10,400
	-H116	Sheet & Plate	0.188 to 1.250	46	33	27	27	10,400
	-H32, H321	Sheet & Plate	0.188 to 0.499	46	33	27	27	10,400
	-H116	Plate	1.251 to 1.500	44	31	25	25	10,400
	-H32, H321	Plate	0.500 to 1.500	44	31	25	25	10,400
	-H116, H32, H321	Plate	1.501 to 3.000	41	29	25	25	10,400
6005	-T5	Extrusions	up thru 1.000	38	35	35	24	10,100
6005A	-T61	Extrusions	up thru 1.000	38	35	35	24	10,100
6061	-T6, T651	Sheet & Plate	0.010 to 4.000	42	35	35	27	10,100
	-T6, T6510, T6511	Extrusions	All	38	35	35	24	10,100
	-T6, T651	Rod & Bar	up thru 8.000	42	35	35	25	10,100
	-T6	Drawn Tube	0.025 to 0.500	42	35	35	27	10,100
	-T6	Pipe	All	38	35	35	24	10,100
6063	-T5	Extrusions	up thru 0.500	22	16	16	13	10,100
	-T5	Extrusions	0.501 to 1.000	21	15	15	12	10,100
	-T52	Extrusions	up thru 1.000	22	16	16	13	10,100
	-T6	Extrusions & Pipe	All	30	25	25	19	10,100
6066	-T6, T6510, T6511	Extrusions	All	50	45	45	27	10,100
6070	-T6, T62	Extrusions	up thru 2.999	48	45	45	29	10,100
6082	-T6, T6511	Extrusions	0.200 thru 6.000	45	38	38	25	10,100
6105	-T5	Extrusions	up thru 0.500	38	35	35	24	10,100
6351	-T5	Extrusions	up thru 1.000	38	35	35	24	10,100
6351	-T6	Extrusions	up thru 0.750	42	37	37	27	10,100
6463	-T6	Extrusions	up thru 0.500	30	25	25	19	10,100
7005	-T53	Extrusions	up thru 0.750	50	44	43	28	10,500

Note: Rod & Bar is rolled or cold finished.

Table A.3.4M
MECHANICAL PROPERTIES FOR WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	PRODUCT	THICKNESS mm	F_{tu} MPa	F_{ty} MPa	F_{cy} MPa	F_{su} MPa	E MPa
1100	-H12	Sheet, Plate, Drawn Tube, Rod & Bar	All	95	75	70	62	69,600
	-H14		All	110	95	90	70	69,600
2014	-T6	Sheet	1.00 to 6.30	455	400	405	275	75,200
	-T651	Plate	6.30 to 50.00	460	405	400	275	75,200
	-T6, T6510, T6511	Extrusions	All	415	365	360	240	75,200
	-T6, T651	Rod & Bar, Drawn Tube	All	450	380	365	260	75,200
Alclad 2014	-T6	Sheet	0.63 to 1.00	435	380	385	260	74,500
	-T6	Sheet	1.00 to 6.30	440	395	400	270	74,500
	-T651	Plate	6.30 to 12.50	440	395	385	270	74,500
3003	-H12	Sheet & Plate	0.40 to 50.00	120	85	70	75	69,600
	-H14	Sheet & Plate	0.20 to 25.00	140	115	95	85	69,600
	-H16	Sheet	0.15 to 4.00	165	145	125	95	69,600
	-H18	Sheet	0.15 to 3.20	185	165	140	105	69,600
	-H12	Drawn Tube	All	120	85	75	75	69,600
	-H14	Drawn Tube	All	140	115	110	85	69,600
	-H16	Drawn Tube	All	165	145	130	95	69,600
	-H18	Drawn Tube	All	185	165	145	105	69,600
Alclad 3003	-H12	Sheet & Plate	0.40 to 50.00	115	80	62	70	69,600
	-H14	Sheet & Plate	0.20 to 25.00	135	110	90	85	69,600
	-H16	Sheet	0.15 to 4.00	160	140	115	95	69,600
	-H18	Sheet	0.15 to 3.20	180	160	130	105	69,600
	-H14	Drawn Tube	0.63 to 6.30	135	110	105	85	69,600
	-H18	Drawn Tube	0.25 to 12.50	180	160	140	105	69,600
3004	-H32	Sheet & Plate	0.40 to 50.00	190	145	125	115	69,600
	-H34	Sheet & Plate	0.20 to 25.00	220	170	150	130	69,600
	-H36	Sheet	0.15 to 4.00	240	190	170	140	69,600
	-H38	Sheet	0.15 to 3.20	260	215	200	145	69,600
	-H34	Drawn Tube	0.45 to 11.50	220	170	165	130	69,600
	-H36	Drawn Tube	0.45 to 11.50	240	190	185	140	69,600
Alclad 3004	-H32	Sheet	0.40 to 6.30	185	140	115	110	69,600
	-H34	Sheet	0.20 to 6.30	215	165	145	125	69,600
	-H36	Sheet	0.15 to 4.00	235	185	165	130	69,600
	-H38	Sheet	0.15 to 3.20	255	205	195	145	69,600
	-H131, H241, H341	Sheet	0.60 to 1.20	215	180	150	125	69,600
	-H151, H261, H361	Sheet	0.60 to 1.20	235	205	195	130	69,600
3005	-H25	Sheet	0.32 to 1.20	180	150	140	105	69,600
	-H28	Sheet	0.15 to 2.00	215	185	170	115	69,600
3105	-H25	Sheet	0.32 to 2.00	160	130	115	95	69,600
5005	-H12	Sheet & Plate	0.40 to 50.00	125	95	90	75	69,600
	-H14	Sheet & Plate	0.20 to 25.00	145	115	105	85	69,600
	-H16	Sheet	0.15 to 4.00	165	135	125	95	69,600
	-H32	Sheet & Plate	0.40 to 50.00	120	85	75	75	69,600
	-H34	Sheet & Plate	0.20 to 25.00	140	105	95	85	69,600
	-H36	Sheet	0.15 to 4.00	160	125	110	90	69,600
5050	-H32	Sheet	0.40 to 6.30	150	110	95	95	69,600
	-H34	Sheet	0.20 to 6.30	170	140	125	105	69,600
	-H32	Rod & Bar, Drawn Tube	All	150	110	105	90	69,600
	-H34	Rod & Bar, Drawn Tube	All	170	140	130	105	69,600
5052	-O	Sheet & Plate	0.15 to 80.00	170	65	65	110	70,300
	-H32	Sheet & Plate, Rod & Bar, Drawn Tube	All	215	160	145	130	70,300
	-H34		All	235	180	165	140	70,300
	-H36	Sheet	0.15 to 4.00	255	200	180	150	70,300

Table A.3.4M
MECHANICAL PROPERTIES FOR WROUGHT ALUMINUM PRODUCTS (Continued)

ALLOY	TEMPER	PRODUCT	THICKNESS mm	F_{tu} MPa	F_{ty} MPa	F_{cy} MPa	F_{su} MPa	E MPa
5083	-O	Extrusions	up thru 13.00	270	110	110	165	71,700
	-H111	Extrusions	up thru 12.70	275	165	145	165	71,700
	-H111	Extrusions	12.70 to 130.00	275	165	145	160	71,700
	-O	Sheet & Plate	1.20 to 6.30	275	125	125	170	71,700
	-H116, H32, H321	Sheet & Plate	4.00 to 40.00	305	215	180	180	71,700
	-H116, H32, H321	Plate	40.00 to 80.00	285	200	165	165	71,700
5086	-O	Extrusions	up thru 130.00	240	95	95	145	71,700
	-H111	Extrusions	up thru 130.00	250	145	125	145	71,700
	-O	Sheet & Plate	0.50 to 50.00	240	95	95	145	71,700
	-H112	Sheet & Plate	4.00 to 12.50	250	125	115	150	71,700
	-H112	Plate	12.50 to 40.00	240	105	110	145	71,700
	-H112	Plate	40.00 to 80.00	235	95	105	145	71,700
	-H116	Sheet & Plate	1.60 to 50.00	275	195	180	165	71,700
	-H32	Sheet & Plate, Drawn Tube	All	275	195	180	165	71,700
	-H34	Sheet & Plate, Drawn Tube	All	300	235	220	180	71,700
5154	-H38	Sheet	0.15 to 3.20	310	240	230	165	71,700
5454	-O	Extrusions	up thru 130.00	215	85	85	130	71,700
	-H111	Extrusions	up thru 12.70	230	130	110	140	71,700
	-H111	Extrusions	12.70 to 130.00	230	130	110	130	71,700
	-H112	Extrusions	up thru 130.00	215	85	90	130	71,700
	-O	Sheet & Plate	0.50 to 80.00	215	85	85	130	71,700
	-H32	Sheet & Plate	0.50 to 50.00	250	180	165	145	71,700
	-H34	Sheet & Plate	0.50 to 25.00	270	200	185	160	71,700
5456	-O	Sheet & Plate	1.20 to 6.30	290	130	130	180	71,700
	-H116, H32, H321	Sheet & Plate	4.00 to 12.50	315	230	185	185	71,700
	-H116, H32, H321	Plate	12.50 to 40.00	305	215	170	170	71,700
	-H116, H32, H321	Plate	40.00 to 80.00	285	200	170	170	71,700
6005	-T5	Extrusions	up thru 25.00	260	240	240	165	69,600
6005A	-T61	Extrusions	up thru 25.00	260	240	240	165	69,600
6061	-T6, T651	Sheet & Plate	0.25 to 100.00	290	240	240	185	69,600
	-T6, T6510, T6511	Extrusions	All	260	240	240	165	69,600
	-T6, T651	Rod & Bar	up thru 200	290	240	240	170	69,600
	-T6	Drawn Tube	0.63 to 12.50	290	240	240	185	69,600
	-T6	Pipe	All	260	240	240	165	69,600
6063	-T5	Extrusions	up thru 12.50	150	110	110	90	69,600
	-T52	Extrusions	up thru 25.00	150	110	110	90	69,600
	-T5	Extrusions	12.50 to 25.00	145	105	105	85	69,600
	-T6	Extrusions & Pipe	All	205	170	170	130	69,600
6066	-T6, T6510, T6511	Extrusions	All	345	310	310	185	69,600
6070	-T6, T62	Extrusions	up thru 80.00	330	310	310	200	69,600
6082	-T6, T6511	Extrusions	5.00 thru 150.00	310	260	260	170	69,600
6105	-T5	Extrusions	up thru 12.50	260	240	240	165	69,600
6351	-T5	Extrusions	up thru 25.00	260	240	240	165	69,600
6351	-T6	Extrusions	up thru 20.00	290	255	255	185	69,600
6463	-T6	Extrusions	up thru 12.50	205	170	170	130	69,600
7005	-T53	Extrusions	up thru 20.00	345	305	295	195	72,400

Note: Rod & Bar is rolled or cold finished

Table A.3.5
MECHANICAL PROPERTIES FOR WELD-AFFECTED ZONES IN WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	PRODUCT	THICKNESS in.	F_{tuw} ksi	F_{tyw} ksi	F_{cyw} ksi	F_{suw} ksi	E ksi
1100	All	Sheet & Plate, Drawn Tube		11	3.5	3.5	8	10,100
1100	All	Rod & Bar		11	3.0	3.0	8	10,100
3003	All	Sheet & Plate, Drawn Tube		14	5	5	10	10,100
Alclad 3003	All	Sheet & Plate, Drawn Tube		13	4.5	4.5	10	10,100
3004	All	Sheet & Plate		22	8.5	8.5	14	10,100
3004	All	Drawn Tube		23	8.5	8.5	14	10,100
Alclad 3004	All	Sheet		21	8	8	13	10,100
3005	All	Sheet		17	6.5	6.5	12	10,100
5005	All	Sheet & Plate		15	5	5	9	10,100
5050	All	Sheet & Plate, Drawn Tube, Rod & Bar		18	6	6	12	10,100
5052	All	Sheet & Plate, Rod & Bar		25	9.5	9.5	16	10,200
5052	All	Drawn Tube		25	10	10	16	10,200
5083	All	Extrusions		39	16	16	24	10,400
5083	All	Sheet & Plate	0.188 to 1.500	40	18	18	24	10,400
5083	All	Plate	1.501 to 3.000	39	17	17	24	10,400
5086	All	Sheet & Plate, Extrusions, Drawn Tube		35	14	14	21	10,400
5154	All	Sheet		30	11	11	19	10,300
5454	All	Sheet & Plate, Extrusions		31	12	12	19	10,400
5456	All	Sheet & Plate	0.188–1.500	42	19	19	26	10,400
5456	All	Plate	1.501–3.000	41	18	17	25	10,400
6005	T5	Extrusions	up thru 1.000	24	13	13	15	10,100
6005A	T61	Extrusions	up thru 1.000	24	13	13	15	10,100
6061	T6, T651, T6510, T6511[1]	All		24	15	15	15	10,100
6061	T6, T651, T6510, T6511[2]	All	over 0.375	24	11	11	15	10,100
6063	T5, T52, T6	All		17	8	8	11	10,100
6082	T6, T6511	Extrusions	0.200 to 6.000	28	16	16	15	10,100
6105	T5	Extrusions	up thru 0.500	24	13	13	15	10,100
6351	T5, T6[1]	Extrusions		24	15	15	15	10,100
6351	T5, T6[2]	Extrusions	over 0.375	24	11	11	15	10,100
6463	T6	Extrusions	up thru 0.500	17	8	8	11	10,100
7005	T53	Extrusions	up thru 0.750	40	24	24	22	10,500

Notes

1. When welded with 5183, 5356, or 5556 alloy filler regardless of thickness, and when welded with 4043, 5554, or 5654 alloy filler for thicknesses ≤ 0.375 in..
2. When welded with 4043, 5554, or 5654 alloy filler.

Table A.3.5M
MECHANICAL PROPERTIES FOR WELD-AFFECTED ZONES IN WROUGHT ALUMINUM PRODUCTS

ALLOY	TEMPER	PRODUCT	THICKNESS mm	F_{tuw} MPa	F_{tyw} MPa	F_{cyw} MPa	F_{suw} MPa	E MPa
1100	All	Sheet & Plate, Drawn Tube		75	25	25	55	69,600
1100	All	Rod & Bar		75	20	20	55	69,600
3003	All	Sheet & Plate, Drawn Tube		95	35	35	70	69,600
Alclad 3003	All	Sheet & Plate, Drawn Tube		90	30	30	70	69,600
3004	All	Sheet & Plate		150	60	60	95	69,600
3004	All	Drawn Tube		160	60	60	95	69,600
Alclad 3004	All	Sheet		145	55	55	90	69,600
3005	All	Sheet		115	45	45	85	69,600
5005	All	Sheet & Plate		105	35	35	62	69,600
5050	All	Sheet & Plate, Drawn Tube, Rod & Bar		125	40	40	85	69,600
5052	All	Sheet & Plate, Rod & Bar		170	65	65	110	70,300
5052	All	Drawn Tube		170	70	70	110	70,300
5083	All	Extrusions		270	110	110	165	71,700
5083	All	Plate	6.30 to 80.00	270	115	115	165	71,700
5086	All	Sheet & Plate, Drawn Tube, Extrusions		240	95	95	145	71,700
5154	All	Sheet		205	75	75	130	71,700
5454	All	Sheet & Plate, Extrusions		215	85	85	130	71,700
5456	All	Plate	6.30 to 38.00	285	125	125	170	71,700
5456	All	Plate	38.00 to 80.00	285	125	120	170	
6005	T5	Extrusions	up thru 25.00	165	90	90	105	69,600
6005A	T61	Extrusions	up thru 25.00	165	90	90	105	69,600
6061	T6, T651, T6510, T6511[1]	All		165	105	105	105	69,600
6061	T6, T651, T6510, T6511[2]	All	over 9.50	165	80	80	105	69,600
6063	T5, T52, T6	All		115	55	55	75	69,600
6082	T6, T6511	Extrusions	5.00 to 150.00	190	110	110	105	69,600
6105	T5	Extrusions	up thru 12.50	165	90	90	105	69,600
6351	T5, T6[1]	Extrusions		165	105	105	105	69,600
6351	T5, T6[2]	Extrusions	over 9.50	165	80	80	105	69,600
6463	T6	Extrusions	up thru 12.50	115	55	55	75	69,600
7005	T53	Extrusions	up thru 20.00	275	165	165	155	72,400

Notes

1. When welded with 5183, 5356, or 5556 alloy filler regardless of thickness, and when welded with 4043, 5554, or 5654 alloy filler for thicknesses ≤ 9.50 mm.
2. When welded with 4043, 5554, or 5654 alloy filler.

Table A.3.6
STRENGTHS OF ALUMINUM CASTINGS

Alloy	Temper	Casting Type	F_{tu} ksi	F_{ty} ksi	Note
356.0	T6	sand	22.5	15	
A356.0	T6	sand	25.5	18	
354.0	T61	permanent mold	36	27.7	(1)
			47	36	(2)
			43	33	(3)
C355.0	T61	permanent mold	30	22.5	(1)
			40	30	(2)
			37	30	(3)
356.0	T6	permanent mold	24.7	16.5	(1)
A356.0	T61	permanent mold	28.5	19.5	(1)
			33	26	(2)
			28	26	(3)
A357.0	T61	permanent mold	33.7	27	(1)
			46	36	(2)
			41	31	(3)
359.0	T61	permanent mold	33.7	25.5	(1)
			45	34	(2)
			40	30	(3)
359.0	T62	permanent mold	35.2	28.5	(1)
			47	38	(2)
			40	30	(3)
535.0	F	permanent mold	26.2	13.5	(1)

See Table A.3.6M

Table A.3.6M
STRENGTHS OF ALUMINUM CASTINGS

Alloy	Temper	Casting Type	F_{tu} MPa	F_{ty} MPa	Note
356.0	T6	sand	154	105	
A356.0	T6	sand	176	124	
354.0	T61	permanent mold	248	191	(1)
			324	248	(2)
			297	228	(3)
C355.0	T61	permanent mold	207	155	(1)
			276	207	(2)
			255	207	(3)
356.0	T6	permanent mold	170	110	(1)
A356.0	T61	permanent mold	196	134	(1)
			228	179	(2)
			193	179	(3)
A357.0	T61	permanent mold	232	186	(1)
			317	248	(2)
			283	214	(3)
359.0	T61	permanent mold	232	175	(1)
			310	234	(2)
			276	207	(3)
359.0	T62	permanent mold	243	196	(1)
			324	262	(2)
			276	207	(3)
535.0	F	permanent mold	180	93	(1)

Notes

1. These strengths apply at any location in the casting if the purchaser does not specify that test specimens be cut from castings.
2. These strengths apply in the locations specified by the purchaser if the purchaser specifies such locations. At other locations, the strengths in (1) apply.
3. These strengths apply anywhere in the casting if the purchaser specifies that these strengths shall be met in specimens cut from the casting without designating a location.

Table A.3.7
RADIOGRAPHIC INSPECTION CRITERIA FOR CASTINGS

Lot Size	Number of Castings Required to be Radiographed	Number of Castings Required to Meet Grade C to Pass Lot
2 through 50	2	2
51 through 500	8	7
over 500	13	11

Table A.3.8
STRENGTHS OF ALUMINUM BOLTS

Alloy and Temper	Shear Ultimate Strength[1] F_{su} (ksi)	Tensile Ultimate Strength[1] F_{tu} (ksi)
2024-T4	37	62
6061-T6	25	42
7075-T73	41	68

Note: 1. From ASTM B 316/B 316M and F 468

Table A.3.8M
STRENGTHS OF ALUMINUM BOLTS

Alloy and Temper	Shear Ultimate Strength[1] F_{su} (MPa)	Tensile Ultimate Strength[1] F_{tu} (MPa)
2024-T4	255	425
6061-T6	170	290
7075-T73	280	470

Note: 1. From ASTM B 316/B 316M

Table A.3.9
STRENGTHS OF ALUMINUM RIVETS

Designation Before Driving	Shear Ultimate Strength F_{su} (ksi) (note 1)
2017-T4	33
2024-T42	37
2117-T4	26
2219-T6	30
6053-T61	20
6061-T6	25
7050-T7	39
7075-T6	42
7075-T73	41
7178-T6	46

Note: 1. From ASTM B 316/B 316M

Table A.3.9M
STRENGTHS OF ALUMINUM RIVETS

Designation Before Driving	Shear Ultimate Strength F_{su} (MPa) (note 1)
2017-T4	225
2024-T42	255
2117-T4	180
2219-T6	205
6053-T61	135
6061-T6	170
7050-T7	270
7075-T6	290
7075-T73	280
7178-T6	315

Note: 1. From ASTM B 316/B 316M

Chapter B Design Requirements

B.1 Section Properties

Section properties such as cross-sectional area, moment of inertia, section modulus, radius of gyration, and torsion and warping constants shall be determined using nominal dimensions. Section properties used to determine bending deflections shall be determined in accordance with Section L.3. Cross section dimensions shall not vary by more than the tolerances given in *Aluminum Standards and Data.*

B.2 Loads and Load Combinations

B.2.1 Building-Type Structures

Building-type structures shall be designed for the nominal loads and load combinations given in the applicable building code or contract documents. In the absence of a building code or contract documents, ASCE 7, *Minimum Design Loads for Buildings and Other Structures,* shall be used.

B.2.2 Bridge-Type Structures

Bridge-type structures shall be designed for the nominal loads and load combinations given in the contract documents. In the absence of contract documents, highway bridges shall be designed for the nominal loads and load combinations given in AASHTO's *Standard Specifications for Highway Bridges,* and pedestrian bridges shall be designed for the nominal loads and load combinations given in AASHTO's *Guide Specifications for Design of Pedestrian Bridges.*

B.2.3 Other Structures

Structural supports for highway signs, luminaires, and traffic signals shall be designed for the loads given in *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals.* Other structures shall be designed for the loads given in the contract documents. In the absence of contract documents, other structures shall be designed for the loads given in ASCE 7 where applicable.

B.3 Design Basis

Designs shall be made according to the provisions for Load and Resistance Factor Design (LRFD) or Allowable Strength Design (ASD). LRFD is limited to building-type structures.

B.3.1 Limit States

No applicable strength or serviceability limit state shall be exceeded by the loads and load combinations given in Section B.2.

B.3.2 Required Strength

The required strength of structural members and connections shall be determined by structural analysis using the loads and load combinations stipulated in Section B.2. Computation of forces, moments, and deflections shall be by elastic analysis in accordance with Chapter C. The effect of eccentricities at connections shall be addressed as required by Section J.1.1.

B.3.2.1 Design for Strength Using Load and Resistance Factor Design (LRFD)

Design using the provisions for Load and Resistance Factor Design (LRFD) meets the requirements of this *Specification* when the design strength of each structural component equals or exceeds the required strength determined on the basis of the LRFD load combinations. All provisions of this *Specification* except Section B.3.2.2 shall apply.

Design shall satisfy Equation B.3-1:

$$R_u \leq \phi R_n \tag{B.3-1}$$

where

R_u = required strength
R_n = nominal strength
ϕ = resistance factor
ϕR_n = design strength

Resistance factors for building-type structures shall be as given in this *Specification.*

B.3.2.2 Design for Strength Using Allowable Strength Design (ASD)

Design using the provisions for Allowable Strength Design (ASD) meets the requirements of this *Specification* when the allowable strength of each structural component equals or exceeds the required strength determined on the basis of the ASD load combinations. All provisions of this *Specification* except Section B.3.2.1 shall apply.

Design shall satisfy Equation B.3-2:

$$R_a \leq R_n/\Omega \tag{B.3-2}$$

where

R_a = required strength
R_n = nominal strength
Ω = safety factor
R_n/Ω = allowable strength

Safety factors for building-type structures and bridge-type structures shall be as given in this *Specification.*

B.3.3 Design for Stability

Stability of the structure and its components shall be determined in accordance with Chapter C.

B.3.4 Design for Serviceability

Structures and their components shall meet the serviceability requirements given in Chapter L.

B.3.5 Design for Fatigue

Structures and their components subjected to repeated loading shall meet the requirements of Appendix 3. Fatigue need not be considered for seismic loads.

B.3.6 Design for Fire Conditions

Design for fire conditions shall meet the requirements of Appendix 4.

B.3.7 Design of Braces

Braces for columns and beams shall meet the requirements of Appendix 6.

B.4 Buckling Constants

Buckling constants *B, D,* and *C* shall be determined from Tables B.4.1 and B.4.2. Postbuckling constants k_1 and k_2 shall be determined from Table B.4.3.

Table B.4.1
BUCKLING CONSTANTS FOR TEMPER DESIGNATIONS BEGINNING WITH O, H, T1, T2, T3, OR T4, AND WELD-AFFECTED ZONES OF ALL TEMPERS

Type of Stress and Member	Intercept	Slope	Intersection
Compression in Columns and Beam Flanges	$B_c = F_{cy}\left(1 + \left(\frac{F_{cy}}{1000\kappa}\right)^{1/2}\right)$	$D_c = \frac{B_c}{20}\left(\frac{6B_c}{E}\right)^{1/2}$	$C_c = \frac{2B_c}{3D_c}$
Axial Compression in Flat Elements	$B_p = F_{cy}\left(1 + \left(\frac{F_{cy}}{440\kappa}\right)^{1/3}\right)$	$D_p = \frac{B_p}{20}\left(\frac{6B_p}{E}\right)^{1/2}$	$C_p = \frac{2B_p}{3D_p}$
Axial Compression in Curved Elements	$B_t = F_{cy}\left(1 + \left(\frac{F_{cy}}{6500\kappa}\right)^{1/5}\right)$	$D_t = \frac{B_t}{3.7}\left(\frac{B_t}{E}\right)^{1/3}$	C_t see note 2
Bending Compression in Flat Elements	$B_{br} = 1.3F_{cy}\left(1 + \left(\frac{F_{cy}}{340\kappa}\right)^{1/3}\right)$	$D_{br} = \frac{B_{br}}{20}\left(\frac{6B_{br}}{E}\right)^{1/2}$	$C_{br} = \frac{2B_{br}}{3D_{br}}$
Bending Compression in Curved Elements	$B_{tb} = 1.5F_{cy}\left(1 + \left(\frac{F_{cy}}{6500\kappa}\right)^{1/5}\right)$	$D_{tb} = \frac{B_{tb}}{2.7}\left(\frac{B_{tb}}{E}\right)^{1/3}$	$C_{tb} = \left(\frac{B_{tb} - B_t}{D_{tb} - D_t}\right)^2$
Shear in Flat Elements	$B_s = F_{sy}\left(1 + \left(\frac{F_{sy}}{240\kappa}\right)^{1/3}\right)$	$D_s = \frac{B_s}{20}\left(\frac{6B_s}{E}\right)^{1/2}$	$C_s = \frac{2B_s}{3D_s}$

Notes
1. κ = 1.0 ksi (6.895 MPa)
2. C_t shall be determined using a plot of curves of limit state stress based on elastic and inelastic buckling or by trial and error solution.

Table B.4.2
BUCKLING CONSTANTS FOR TEMPER DESIGNATIONS BEGINNING WITH T5, T6, T7, T8, OR T9

Type of Stress and Member	Intercept	Slope	Intersection
Compression in Columns and Beam Flanges	$B_c = F_{cy}\left(1 + \left(\frac{F_{cy}}{2250\kappa}\right)^{1/2}\right)$	$D_c = \frac{B_c}{10}\left(\frac{B_c}{E}\right)^{1/2}$	$C_c = 0.41\frac{B_c}{D_c}$
Axial Compression in Flat Elements	$B_p = F_{cy}\left(1 + \left(\frac{F_{cy}}{1500\kappa}\right)^{1/3}\right)$	$D_p = \frac{B_p}{10}\left(\frac{B_p}{E}\right)^{1/2}$	$C_p = 0.41\frac{B_p}{D_p}$
Axial Compression in Curved Elements	$B_t = F_{cy}\left(1 + \left(\frac{F_{cy}}{50{,}000\kappa}\right)^{1/5}\right)$	$D_t = \frac{B_t}{4.5}\left(\frac{B_t}{E}\right)^{1/3}$	C_t see note 2
Bending Compression in Flat Elements	$B_{br} = 1.3F_{cy}\left(1 + \left(\frac{F_{cy}}{340\kappa}\right)^{1/3}\right)$	$D_{br} = \frac{B_{br}}{20}\left(\frac{6B_{br}}{E}\right)^{1/2}$	$C_{br} = \frac{2B_{br}}{3D_{br}}$
Bending Compression in Curved Elements	$B_{tb} = 1.5F_{cy}\left(1 + \left(\frac{F_{cy}}{50{,}000\kappa}\right)^{1/5}\right)$	$D_{tb} = \frac{B_{tb}}{2.7}\left(\frac{B_{tb}}{E}\right)^{1/3}$	$C_{tb} = \left(\frac{B_{tb} - B_t}{D_{tb} - D_t}\right)^2$
Shear in Flat Elements	$B_s = F_{sy}\left(1 + \left(\frac{F_{sy}}{800\kappa}\right)^{1/3}\right)$	$D_s = \frac{B_s}{10}\left(\frac{B_s}{E}\right)^{1/2}$	$C_s = 0.41\frac{B_s}{D_s}$

Notes
1. κ = 1.0 ksi (6.895 MPa)
2. C_t shall be determined using a plot of curves of limit state stress based on elastic and inelastic buckling or by trial and error solution.

Table B.4.3
POSTBUCKLING CONSTANTS

Type of Element	k_1	k_2
Flat Elements in Compression for Temper Designations Beginning with O, H, T1, T2, T3, or T4, and weld-affected zones of all tempers	0.50	2.04
Flat Elements in Compression for Temper Designations Beginning with T5, T6, T7, T8, or T9	0.35	2.27
Flat Elements in Flexure	0.50	2.04

B.5 Elements

B.5.1 Width of Flat Elements and Stiffeners

For flat elements:

a) supported on one edge, the element width *b* is the distance from the element's unsupported edge to the toe of the fillet or bend at the element's supported edge (Figure B.5.1)

b) supported on both edges and flat elements supported on one edge and with a stiffener on the other edge, the element width *b* is the distance between the toes of the fillets or bends at the element's supported or stiffened edges (Figures B.5.2 and B.5.3).

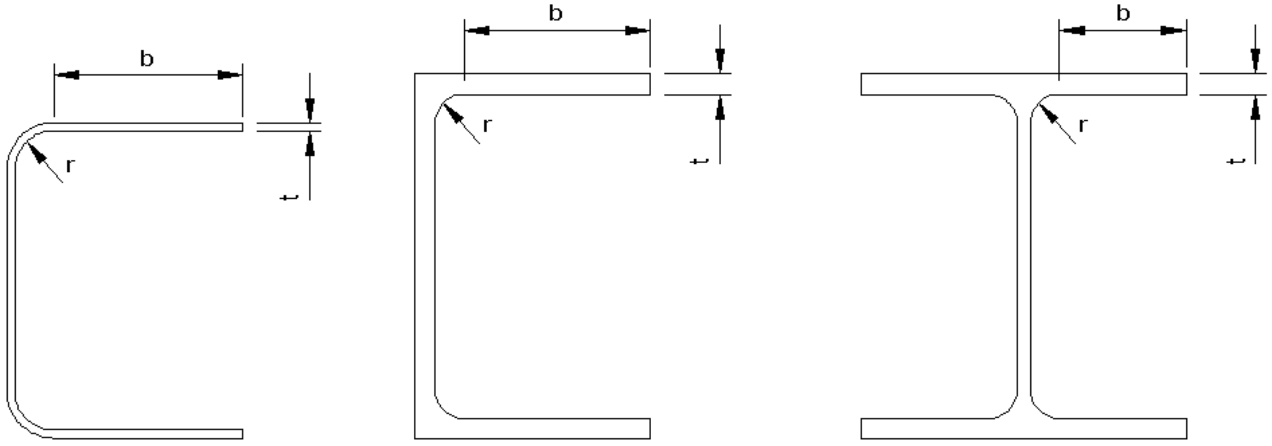
c) supported on both edges and with an intermediate stiffener, the element width *b* is the largest distance between the toe of the fillet or bend at the element's supported edge and the toe of the fillet or bend at the intermediate stiffener (Figure B.5.4).

For all flat elements, if the inside corner radius exceeds 4 times the element thickness, the inside radius shall be assumed equal to 4 times the thickness in calculating *b*.

Dimensions and properties of stiffeners shall be determined in accordance with Figures B.5.3 and B.5.4.

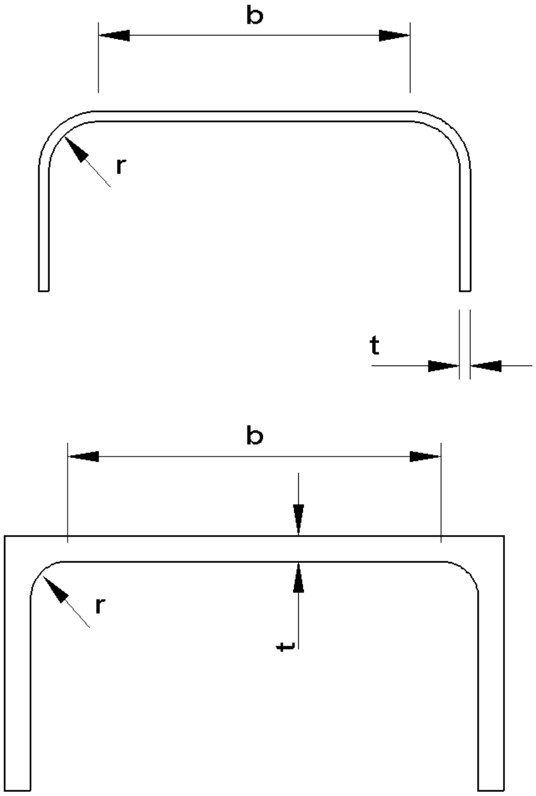
B.5.2 Radius of Curved Elements

The radius of curved elements R_b shall be taken at the mid-thickness of the element.



If $r > 4t$, use $r = 4t$ to calculate b.

Figure B.5.1
FLAT ELEMENTS SUPPORTED ON ONE EDGE



If $r > 4t$, use $r = 4t$ to calculate b.

Figure B.5.2
FLAT ELEMENTS SUPPORTED ON BOTH EDGES

B.5.3 Thickness of Elements

For uniform compression on elements with linearly varying thickness with $\delta \le 2.0$:

a) For tapered thickness elements with the thick edge supported and the thin edge free, the slenderness ratio is $(1 - 0.12\delta)(b/t_{avg})$.
b) For tapered thickness elements with the thin edge supported and the thick edge free, the slenderness ratio is (b/t_{avg})
c) For tapered thickness elements supported on both edges, the slenderness ratio is (b/t_{avg}).

where

b = element width

$$t_{avg} = \frac{t_{max} + t_{min}}{2} \tag{B.5-1}$$

= average thickness of the element
t_{min} = minimum thickness of the tapered thickness element
t_{max} = maximum thickness of the tapered thickness element

$$\delta = \frac{(t_{max} - t_{min})}{t_{min}} \tag{B.5-2}$$

B.5.4 Strength of Elements in Uniform Compression

For elements in uniform compression, the stress corresponding to the uniform compression strength is

For unwelded members:

$$F_c = F_{co} \tag{B.5-3}$$

For welded members:

$$F_c = F_{co}(1 - A_{wz}/A_g) + F_{cw}A_{wz}/A_g \tag{B.5-4}$$

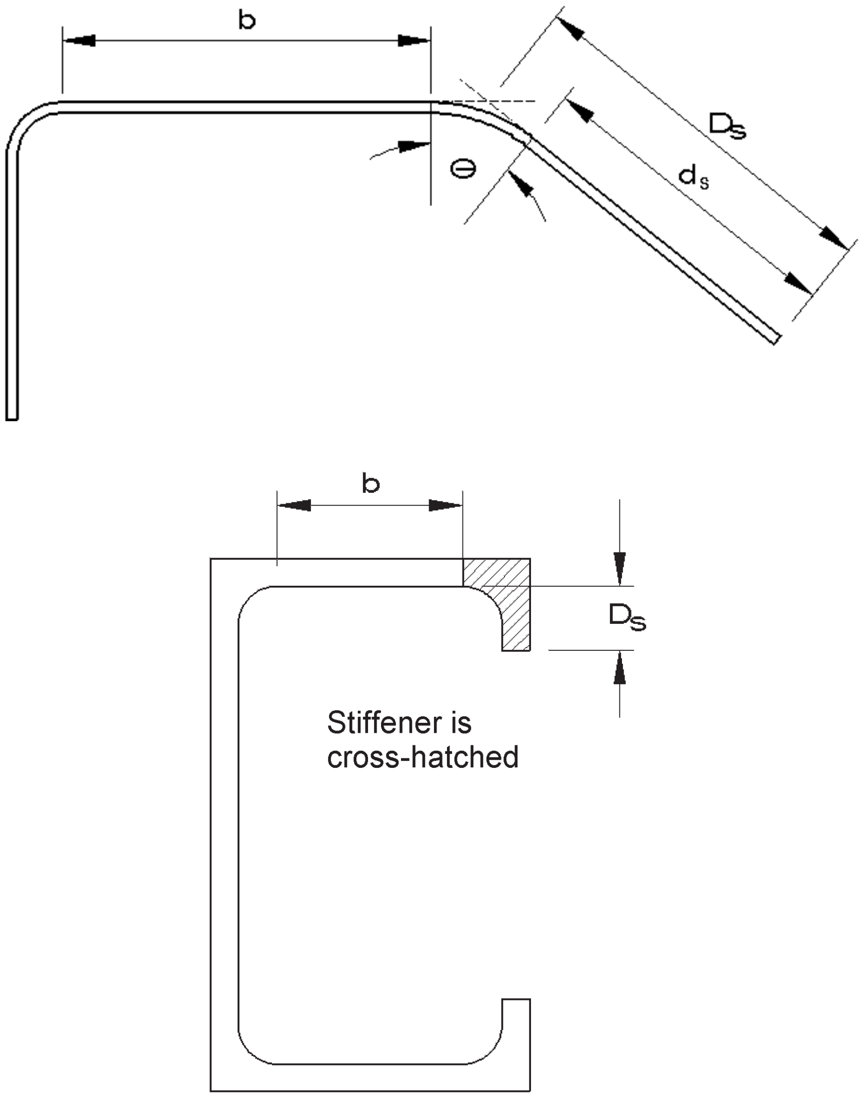
where

F_{co} = stress corresponding to the uniform compression strength calculated using Sections B.5.4.1 through B.5.4.5 for an element if no part of the cross section were weld-affected. Use buckling constants for unwelded metal (Table B.4.1 or Table B.4.2) and strengths from Table A.3.4 or Table A.3.4M.
F_{cw} = stress corresponding to the uniform compression strength calculated using Sections B.5.4.1 through B.5.4.5 for an element if the entire cross section were weld-affected. Use buckling constants for weld-affected zones (Table B.4.1) and strengths from Table A.3.5 or Table A.3.5M. For transversely welded elements with $b/t \le S_1$, $F_c = F_{co}$.
A_{wz} = cross sectional area of the weld-affected zone
A_g = gross cross sectional area of the element.

B.5.4.1 Flat Elements Supported On One Edge

The stress F_c corresponding to the uniform compression strength of flat elements supported on one edge is:

Limit State	F_c	b/t	Slenderness Limits
yielding	F_{cy}	$b/t \le S_1$	$S_1 = \dfrac{B_p - F_{cy}}{5.0D_p}$
inelastic buckling	$B_p - 5.0D_p\, b/t$	$S_1 < b/t < S_2$	
in columns whose buckling axis is not an axis of symmetry:			
elastic buckling	$\dfrac{\pi^2 E}{(5.0b/t)^2}$	$b/t \ge S_2$	$S_2 = \dfrac{C_p}{5.0}$
in all other columns and all beams:			
post-buckling	$\dfrac{k_2\sqrt{B_p E}}{5.0b/t}$	$b/t \ge S_2$	$S_2 = \dfrac{k_1 B_p}{5.0D_p}$



If $r > 4t$, use $r = 4t$ to calculate b.

Figure B.5.3
EDGE STIFFENED ELEMENTS

B.5.4.2 Flat Elements Supported on Both Edges

The stress F_c corresponding to the uniform compression strength of flat elements supported on both edges is:

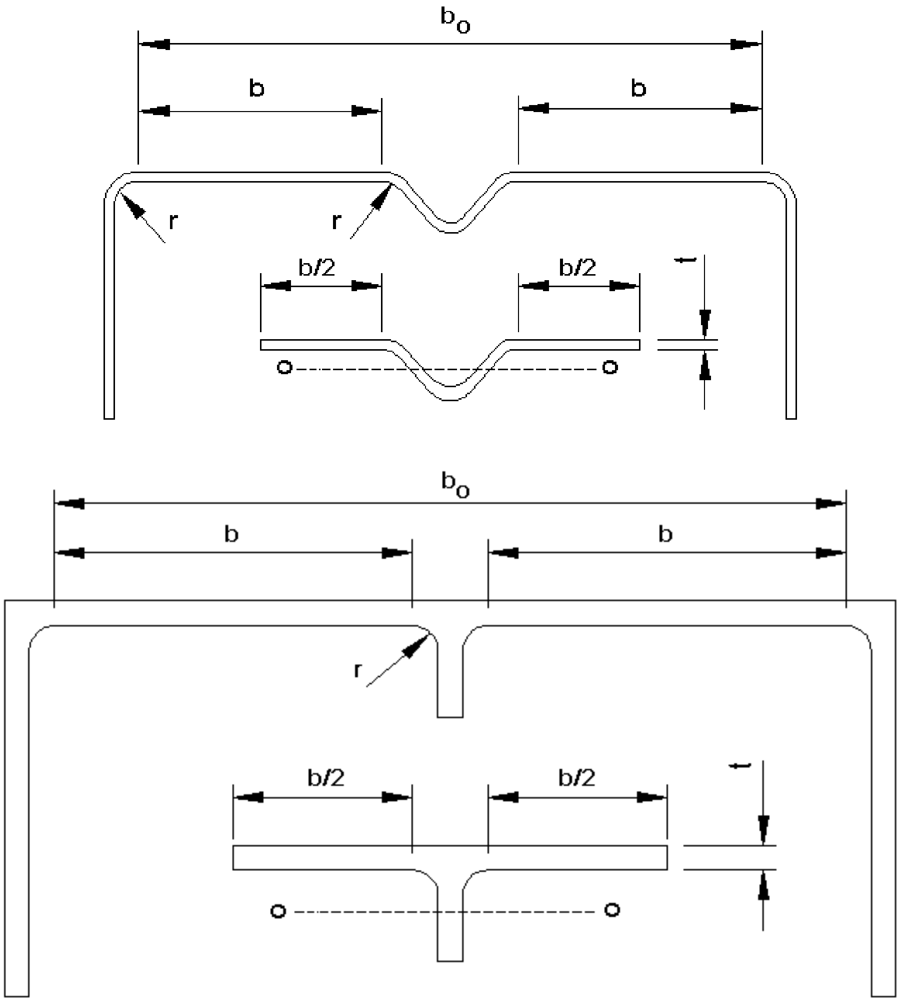
Limit State	F_c	b/t	Slenderness Limits
yielding	F_{cy}	$b/t \le S_1$	$S_1 = \frac{B_p - F_{cy}}{1.6D_p}$
inelastic buckling	$B_p - 1.6D_p\, b/t$	$S_1 < b/t < S_2$	
post-buckling	$\frac{k_2\sqrt{B_pE}}{1.6b/t}$	$b/t \ge S_2$	$S_2 = \frac{k_1 B_p}{1.6D_p}$

B.5.4.3 Flat Elements Supported on One Edge and with a Stiffener on the Other Edge

For flat elements

a) supported on one edge and with a stiffener on the other edge,
b) with a stiffener of depth $D_S \le 0.8b$, where D_S is defined in Figure B.5.3, and
c) with a thickness no greater than the stiffener's thickness, the stress corresponding to the uniform compression strength is

$$F_c = F_{UT} + (F_{ST} - F_{UT})\rho_{ST} \tag{B.5-5}$$



Line o-o is the neutral axis of the stiffener and element of width *b*/2 on each side of the stiffener. I_o is the moment of inertia of the portion shown in the partial section.

If $r > 4t$, use $r = 4t$ to calculate b.

Figure B.5.4
FLAT ELEMENTS WITH AN INTERMEDIATE STIFFENER

where

F_{UT} is determined using Section B.5.4.1 and neglecting the stiffener

F_{ST} is determined using Section B.5.4.2

ρ_{ST} = stiffener effectiveness ratio determined as follows:

a) $\rho_{ST} = 1.0$ for $b/t \le S_e/3$ (B.5-6)

b) $$\rho_{ST} = \frac{r_s}{9t\left(\frac{b/t}{S_e} - \frac{1}{3}\right)} \le 1.0 \quad \text{for } S_e/3 < b/t \le S_e \qquad \text{(B.5-7)}$$

c) $$\rho_{ST} = \frac{r_s}{1.5t\left(\frac{b/t}{S_e} + 3\right)} \le 1.0 \quad \text{for } S_e < b/t < 2S_e \qquad \text{(B.5-8)}$$

r_s = the stiffener's radius of gyration about the stiffened element's mid-thickness. For straight stiffeners of constant thickness (see Figure B.5.3) $r_s = d_s (\sin\theta)/\sqrt{3}$ where d_s = the stiffener's flat width and θ = the angle between the stiffener and the stiffened element.

$$S_e = 1.28\sqrt{E/F_{cy}} \qquad \text{(B.5-9)}$$

F_c for the stiffened element determined using Section B.5.4.3 shall not exceed F_c for the stiffener determined using Section B.5.4.1.

For flat elements

a) supported on one edge and with a stiffener on the other edge, and

b) with a stiffener of depth $D_S > 0.8b$, where D_S is defined in Figure B.5.3, or with a thickness greater than the stiffener's thickness, the stress corresponding to the uniform compression strength is $F_c = F_{UT}$.

B.5.4.4 Flat Elements Supported on Both Edges and with an Intermediate Stiffener

The stress F_c corresponding to the uniform compression strength of flat elements supported on both edges and with an intermediate stiffener is:

Limit State	F_c	λ_s	Slenderness Limits
yielding	F_{cy}	$\lambda_s \le S_1$	$S_1 = \dfrac{B_c - F_{cy}}{D_c}$
inelastic buckling	$B_c - D_c\,\lambda_s$	$S_1 < \lambda_s < S_2$	
elastic buckling	$\dfrac{\pi^2 E}{\lambda_s^2}$	$\lambda_s \ge S_2$	$S_2 = C_c$

where

$$\lambda_s = 4.62\left(\frac{b}{t}\right)\sqrt{\frac{1 + A_s/(bt)}{1 + \sqrt{1 + \dfrac{10.67 I_o}{bt^3}}}} \qquad \text{(B.5-10)}$$

A_s = area of the stiffener

I_o = moment of inertia of a section comprising the stiffener and one half of the width of the adjacent sub-elements and the transition corners between them taken about the centroidal axis of the section parallel to the stiffened element (Figure B.5.4).

F_c shall not exceed F_c determined using Section B.5.4.2 for the sub-elements of the stiffened element.

F_c need not be less than F_c determined using Section B.5.4.2 and neglecting the stiffener.

B.5.4.5 Curved Elements Supported on Both Edges

The stress F_c corresponding to the uniform compression strength of curved elements supported on both edges is:

Limit State	F_c	R_b/t	Slenderness Limits
yielding	F_{cy}	$R_b/t \le S_1$	$S_1 = \left(\dfrac{B_t - F_{cy}}{D_t}\right)^2$
inelastic buckling	$B_t - D_t\sqrt{\dfrac{R_b}{t}}$	$S_1 < R_b/t < S_2$	
elastic buckling	$\dfrac{\pi^2 E}{16\left(\dfrac{R_b}{t}\right)\left(1+\dfrac{\sqrt{R_b/t}}{35}\right)^2}$	$R_b/t \ge S_2$	$S_2 = C_t$

For tubes with circumferential welds, use of Section B.5.4.5 is limited by Sections E.6.1 and F.9.1.

B.5.4.6 Flat Elements Alternate Method

As an alternate to Sections B.5.4.1 through B.5.4.4, the stress F_c corresponding to the uniform compression strength of flat elements without welds may be determined as:

Limit State	F_c	λ_{eq}	Slenderness Limits
yielding	F_{cy}	$\lambda_{eq} \le S_1$	$S_1 = \dfrac{B_p - F_{cy}}{D_p}$
inelastic buckling	$B_p - D_p\lambda_{eq}$	$S_1 < \lambda_{eq} < S_2$	
post-buckling	$\dfrac{k_2\sqrt{B_p E}}{\lambda_{eq}}$	$\lambda_{eq} \ge S_2$	$S_2 = \dfrac{k_1 B_p}{D_p}$

$$\lambda_{eq} = \pi\sqrt{\frac{E}{F_e}} \qquad \text{(B.5-11)}$$

F_e = the elastic local buckling stress of the cross section determined by analysis

B.5.5 Strength of Elements in Flexure

For elements in flexure, the stress corresponding to the flexural compression strength is

For unwelded members:

$$F_b = F_{bo} \qquad \text{(B.5-12)}$$

For welded members:

$$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw} A_{wzc}/A_{gc} \qquad \text{(B.5-13)}$$

where

F_{bo} = stress corresponding to the flexural compression strength calculated using Sections B.5.5.1 through B.5.5.3 for an element if no part of the cross section were weld-affected. Use buckling constants for unwelded metal (Table B.4.1 or Table B.4.2) and mechanical properties from Table A.3.4 or Table A.3.4M.

F_{bw} = stress corresponding to the flexural compression strength calculated using Sections B.5.5.1 through B.5.5.3 for an element if the entire cross section were weld-affected. Use buckling constants for weld-affected zones (Table B.4.1) and mechanical properties from Table A.3.5 or Table A.3.5M. For transversely welded elements with $b/t \le S_1$, $F_b = F_{bo}$.

A_{wzc} = cross sectional area of the weld-affected zone in compression

A_{gc} = gross cross sectional area of the element in compression.

B.5.5.1 Flat Elements Supported on Both Edges

The stress F_b corresponding to the flexural compression strength of flat elements supported on both edges and flat elements supported on the compression edge with the tension edge free is:

Limit State	F_b	b/t	Slenderness Limits
yielding	$1.3F_{cy}$	$b/t \le S_1$	$S_1 = \dfrac{B_{br} - 1.3F_{cy}}{mD_{br}}$
inelastic buckling	$B_{br} - mD_{br}\, b/t$	$S_1 < b/t < S_2$	
post-buckling	$\dfrac{k_2\sqrt{B_{br}E}}{(mb/t)}$	$b/t \ge S_2$	$S_2 = \dfrac{k_1 B_{br}}{mD_{br}}$

$m = 1.15 + c_o/(2c_c)$ for $-1 < c_o/c_c < 1$

$m = 1.3/(1 - c_o/c_c)$ for $c_o/c_c \le -1$

$m = 0.65$ for $c_c = -c_o$

c_c = distance from neutral axis to the element extreme fiber with the greatest compression stress

c_o = distance from neutral axis to other extreme fiber of the element

Distances to compressive fibers are negative and distances to tensile fibers are positive.

B.5.5.2 Flat Elements Supported on Tension Edge, Compression Edge Free

The stress F_b corresponding to the flexural compression strength of flat elements supported on the tension edge with the compression edge free is:

Limit State	F_b	b/t	Slenderness Limits
yielding	$1.3F_{cy}$	$b/t \le S_1$	$S_1 = \dfrac{B_{br} - 1.3F_{cy}}{3.5D_{br}}$
inelastic buckling	$B_{br} - 3.5D_{br}\, b/t$	$S_1 < b/t < S_2$	
elastic buckling	$\dfrac{\pi^2 E}{(3.5b/t)^2}$	$b/t \ge S_2$	$S_2 = \dfrac{C_{br}}{3.5}$

B.5.5.3 Flat Elements Supported on Both Edges and with a Longitudinal Stiffener

The stress F_b corresponding to the flexural compression strength of elements supported on both edges and with a longitudinal stiffener located $0.4d_1$ from the supported edge that is in compression is:

Limit State	F_b	b/t	Slenderness Limits
yielding	$1.3F_{cy}$	$b/t \le S_1$	$S_1 = \dfrac{B_{br} - 1.3F_{cy}}{0.29D_{br}}$
inelastic buckling	$B_{br} - 0.29D_{br}\, b/t$	$S_1 < b/t < S_2$	
post-buckling	$\dfrac{k_2\sqrt{B_{br}E}}{(0.29b/t)}$	$b/t \ge S_2$	$S_2 = \dfrac{k_1 B_{br}}{0.29D_{br}}$

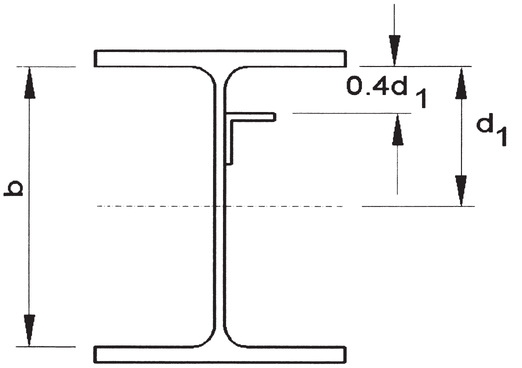


Figure B.5.5
FLAT ELEMENT WITH A LONGITUDINAL STIFFENER

The moment of inertia of the longitudinal stiffener I_L about the web of the beam shall equal or exceed

$$I_L = \frac{0.02\alpha_s f t b^3}{E}\left[\left(1 + \frac{6A_L}{bt}\right)\left(\frac{s}{b}\right)^2 + 0.4\right] \qquad \text{(B.5-14)}$$

where (see Figure B.5.5)

A_L = cross-sectional area of the longitudinal stiffener

d_1 = distance from the neutral axis to the compression flange

f = compressive stress at the toe of the flange

b = clear height of the web

s = distance between transverse stiffeners

t = web thickness

α_s = 1 for a stiffener consisting of equal members on both sides of the web

= 3.5 for a stiffener consisting of a member on only one side of the web

For a stiffener consisting of equal members on both sides of the web, the moment of inertia I_L shall be the sum of the moments of inertia about the centerline of the web. For a stiffener consisting of a member on one side of the web only, the moment of inertia I_L shall be taken about the face of the web in contact with the stiffener.

B.5.5.4 Flat Elements Alternate Method

As an alternate to Sections B.5.5.1 through B.5.5.3 for flat elements in flexure without welds, the stress F_b corresponding to the flexural strength may be determined as:

Limit State	F_b	λ_{eq}	Slenderness Limits
yielding	$1.3F_{cy}$	$\lambda_{eq} \le S_1$	$S_1 = \dfrac{B_{br} - 1.3F_{cy}}{D_{br}}$
inelastic buckling	$B_{br} - D_{br}\lambda_{eq}$	$S_1 < \lambda_{eq} < S_2$	
post-buckling	$\dfrac{k_2\sqrt{B_{br}E}}{\lambda_{eq}}$	$\lambda_{eq} \ge S_2$	$S_2 = \dfrac{k_1 B_{br}}{D_{br}}$

$$\lambda_{eq} = \pi \sqrt{\frac{E}{F_e}} \tag{B.5-15}$$

F_e = the elastic local buckling stress of the cross section determined by analysis

B.5.6 Elastic Buckling Stress of Elements

The elastic buckling stress of elements shall be determined using Table B.5.1.

B.6 Fabrication and Erection

Fabrication and erection shall meet the requirements in Chapter M.

B.7 Evaluation of Existing Structures

Evaluation of existing structures shall meet the requirements in Appendix 5.

Table B.5.1
ELASTIC BUCKLING STRESS F_e OF ELEMENTS

Element Type	Element Stress	Element Support	F_e
flat	uniform compression	supported on both edges	$\frac{\pi^2 E}{(1.6b/t)^2}$
flat	uniform compression	supported on one edge	$\frac{\pi^2 E}{(5.0b/t)^2}$
flat	uniform compression	supported on one edge and with a stiffener on the other edge	$(1 - \rho_{ST})\frac{\pi^2 E}{(5.0b/t)^2} + \rho_{ST}\frac{\pi^2 E}{(1.6b/t)^2}$
flat	uniform compression	supported on both edges and with an intermediate stiffener	$\frac{\pi^2 E}{\lambda_s^2}$
curved	uniform compression	supported on both edges	$\frac{\pi^2 E}{16\left(\frac{R_b}{t}\right)\left(1 + \frac{\sqrt{R_b/t}}{35}\right)^2}$

Note: λ_s is determined from equation B.5-10

Chapter C Design for Stability

This chapter addresses requirements for the analysis and design of structures for stability.

C.1 General Stability Requirements

Stability shall be provided for the structure as a whole and for each of its components. The available strengths of members and connections determined in accordance with Section C.3 shall equal or exceed the required strengths determined in accordance with Section C.2

C.2 Calculation of Required Strengths

The required strengths of members and connections of the structure shall be determined from an elastic analysis that considers the effects of each of the following:

1) Flexural, shear, and axial deformations, including all member and connection deformations that contribute to displacements of the structure;
2) Second-order effects including P-Δ effects (the effect of loads acting on the displaced location of joints or nodes in a structure) and P-δ effects (the effect of loads acting on the deflected shape of a member between joints or nodes);
3) Geometric imperfections. The effect of geometric imperfections on the stability of the structure shall be accounted for by analyzing the structure with the members' points of intersection displaced from their nominal locations by the tolerances specified in the contract documents. The displacements shall be placed to cause the greatest destabilizing effect.
4) Member stiffness reduction due to inelasticity. The effect of member stiffness reduction due to inelasticity on the stability of the structure shall be accounted for by using a reduced stiffness as follows:

   A factor τ_b shall be applied to the flexural stiffnesses of all members whose flexural stiffnesses contribute to the stability of the structure, where

   $\tau_b = 1.0$ for $\alpha\, P_r/P_y \leq 0.5$
   $\tau_b = 4(\alpha\, P_r/P_y)\,(1 - \alpha\, P_r/P_y)$ for $\alpha\, P_r/P_y > 0.5$
   P_r = required axial compressive strength using LRFD or ASD load combinations
   P_y = axial yield strength
   $\alpha = 1.0$ (LRFD); $\alpha = 1.6$ (ASD)
5) Uncertainty in stiffness and strength shall be addressed by applying a factor of 0.8 to all axial, shear, and flexural stiffnesses in the structure.

The analysis shall include all gravity loads, including loads on elements that are not part of the lateral load-resisting system. Analysis shall be conducted for either:

a) The LRFD load combinations with the results used directly to obtain the required strengths, or
b) 1.6 times the ASD load combinations with the results divided by 1.6 to obtain the required strengths.

C.3 Calculation of Available Strengths

The available strengths of members and connections shall be determined in accordance with the provisions of Chapters D, E, F, G, H, and J. The effective length factor k of all members shall be taken as 1.

Bracing intended to define the unbraced length of members shall have sufficient stiffness and strength to control member movement at the brace points.

Chapter D Design of Members for Tension

This chapter addresses members subjected to axial tension through the centroidal axis.

D.1 General Provisions

The design tensile strength $\phi_t P_n$ and the allowable tensile strength P_n/Ω_t of tension members shall be determined in accordance with chapter D where

Limit State	ϕ_t building-type structures	Ω_t building-type structures	Ω_t bridge-type structures
tensile rupture	0.75	1.95	2.20
tensile yielding	0.90	1.65	1.85

D.2 Tensile Strength

The nominal tensile strength P_n of tension members shall be determined as follows.

a) For tensile yielding in the gross section:

For unwelded members and members with transverse welds

$$P_n = F_{ty} A_g \tag{D.2-1}$$

For members with longitudinal welds

$$P_n = F_{ty}(A_g - A_{wz}) + F_{tyw} A_{wz} \tag{D.2-2}$$

b) For tensile rupture in the net section:

For unwelded members

$$P_n = F_{tu} A_e / k_t \tag{D.2-3}$$

For welded members

$$P_n = F_{tu}(A_e - A_{wz})/k_t + F_{tuw} A_{wz} \tag{D.2-4}$$

Block shear rupture strength for the end connections of tension members is given in Section J.6.3.

D.3 Area Determination

D.3.1 Net Area

The net area A_n of a member is the sum of the products of the thickness and the least net width of each element computed as follows:

The width of holes shall be taken as the nominal hole diameter for drilled or reamed holes and the nominal hole diameter plus 1⁄32 in. (0.8 mm) for punched holes.

For a chain of holes extending across a part in any diagonal or zigzag line, the net width of the part shall be obtained by deducting from the gross width the sum of the hole widths of all holes in the chain, and adding, for each gage space in the chain, the quantity $s^2/4g$ where

s = longitudinal center-to-center spacing (pitch) of any two consecutive holes
g = transverse center-to-center spacing (gage) between fastener gage lines

For angles, the gage for holes in opposite legs shall be the sum of the gages from the back of the angles less the thickness.

Weld metal in plug or slot welds shall not be included in the net area.

D.3.2 Effective Net Area

The effective net area A_e for angles, channels, tees, zees, and I-shaped sections shall be determined as follows:

a) If tension is transmitted directly to each of the cross-sectional elements of the member by fasteners or welds, the effective net area A_e is the net area.
b) If tension is transmitted by fasteners or welds through some but not all of the cross-sectional elements of the member, the effective net area A_e is:

$$A_e = A_n\left(1 - \frac{\bar{x}}{L_C}\right)\left(1 - \frac{\bar{y}}{L_C}\right) \tag{D.3-1}$$

where

A_n = net area of the member at the connection
L_C = length of the connection in the direction of load, measured from the center of fasteners or the end of welds. If the length of the connection L_C is zero, the net effective area is the net area of the connected elements.
$\bar{x}$ = eccentricity of the connection in the x-axis direction
$\bar{y}$ = eccentricity of the connection in the y-axis direction

Chapter E Design of Members for Compression

This chapter addresses members subjected to axial compression through the centroidal axis.

E.1 General Provisions

The design compressive strength $\phi_c P_n$ and the allowable compressive strength P_n/Ω_c are the least value for the limit states of member buckling (E.3), local buckling (E.4), and the interaction between member buckling and local buckling (E.5), where

$\phi_c = 0.90$ (LRFD)
$\Omega_c = 1.65$ (ASD building-type structures)
$\Omega_c = 1.85$ (ASD bridge-type structures)

Buckling constants are given in Tables B.4.1, B.4.2, and B.4.3. For weld-affected members see Section E.6.

E.2 Effective Length

The effective length factor k for calculating column slenderness kL/r shall be determined in accordance with Section C.3.

E.3 Member Buckling

The nominal member buckling strength P_n is

$$P_n = F_c A_g \tag{E.3-1}$$

where

$$\text{for } kL/r < S_2,\ F_c = 0.85(B_c - D_c\, kL/r) \le F_{cy} \tag{E.3-2}$$

$$\text{for } kL/r \ge S_2,\ F_c = \frac{0.85\,\pi^2 E}{\left(\frac{kL}{r}\right)^2} \tag{E.3-3}$$

kL/r = greatest column slenderness determined from Sections E.3.1 and E.3.2.

$$S_2 = C_c \tag{E.3-4}$$

E.3.1 Flexural Buckling

For flexural buckling, kL/r is the largest slenderness ratio of the column.

E.3.2 Torsional and Flexural-Torsional Buckling

For torsional or flexural-torsional buckling, kL/r is the larger of the slenderness ratio for flexural buckling and the equivalent slenderness ratio determined as follows:

$$\left(\frac{kL}{r}\right)_e = \pi\sqrt{\frac{E}{F_e}} \tag{E.3-5}$$

where F_e is the elastic buckling stress determined as follows:

a) For doubly symmetric members:

$$F_e = \left(\frac{\pi^2 E C_w}{(k_z L_z)^2} + GJ\right)\frac{1}{I_x + I_y} \tag{E.3-6}$$

b) For singly symmetric members where y is the axis of symmetry:

$$F_e = \left(\frac{F_{ey} + F_{ez}}{2H}\right)\left[1 - \sqrt{1 - \frac{4F_{ey}F_{ez}H}{(F_{ey} + F_{ez})^2}}\right] \tag{E.3-7}$$

c) For unsymmetric members, F_e is the lowest root of the cubic equation:

$$(F_e - F_{ex})(F_e - F_{ey})(F_e - F_{ez}) - F_e^2(F_e - F_{ey})(x_o/r_o)^2 - F_e^2(F_e - F_{ex})(y_o/r_o)^2 = 0 \tag{E.3-8}$$

where

$$r_o^2 = x_o^2 + y_o^2 + \frac{I_x + I_y}{A_g} \tag{E.3-9}$$

$$H = 1 - \frac{x_o^2 + y_o^2}{r_o^2} \tag{E.3-10}$$

$$F_{ex} = \frac{\pi^2 E}{\left(\frac{k_x L_x}{r_x}\right)^2} \tag{E.3-11}$$

$$F_{ey} = \frac{\pi^2 E}{\left(\frac{k_y L_y}{r_y}\right)^2} \tag{E.3-12}$$

$$F_{ez} = \frac{1}{A_g r_o^2}\left(GJ + \frac{\pi^2 E C_w}{(k_z L_z)^2}\right) \tag{E.3-13}$$

I_x, I_y = moments of inertia about the principal axes
x_o, y_o = coordinates of the shear center with respect to the centroid
r_o = polar radius of gyration about the shear center
r_x, r_y = radii of gyration about the centroidal principal axes

E.4 Local Buckling

For members without welds, the local buckling strength shall be determined in accordance with either Section E.4.1 or E.4.2. For members with welds, the local buckling strength shall be determined in accordance with Section E.4.1.

E.4.1 Weighted Average Local Buckling Strength

The weighted average local buckling strength is

$$P_n = \sum_{i=1}^{n} F_{ci} A_i + F_{cy}\left(A_g - \sum_{i=1}^{n} A_i\right) \qquad \text{(E.4-1)}$$

where

F_{ci} = local buckling stress of element i computed per Sections B.5.4.1 through B.5.4.5.
A_i = area of element i

E.4.2 Alternate Local Buckling Strength

As an alternate to Section E.4.1, the local buckling strength of a shape composed of flat elements may be determined as:

$$P_n = F_c A_g \qquad \text{(E.4-2)}$$

where F_c is determined in accordance with Section B.5.4.6.

E.5 Interaction Between Member Buckling and Local Buckling

If the elastic local buckling stress F_e is less than the member buckling stress F_c, the nominal compressive strength of the member shall not exceed

$$P_n = \left[\frac{0.85\pi^2 E}{(kL/r)^2}\right]^{1/3} F_e^{2/3} A_g \qquad \text{(E.5-1)}$$

If the local buckling strength is determined from Section E.4.1, F_e is the smallest elastic local buckling stress for all elements of the cross section according to Table B.5.1.

If the local buckling strength is determined from Section E.4.2, F_e is the elastic local buckling stress of the cross section determined by analysis.

E.6 Welded Compression Members

E.6.1 Compression Members with Transverse Welds

The nominal member buckling strength of a member supported at both ends with no transverse weld farther than 0.05L from the member ends shall be calculated as if there were no welds.

The nominal member buckling strength of a member supported at both ends with a transverse weld farther than 0.05L from the member ends and a member supported at only one end with a transverse weld shall be calculated as if the entire cross sectional area were weld-affected.

For tubes with circumferential welds, Section B.5.4.5 only applies if $R_b/t \le 20$.

E.6.2 Compression Members with Longitudinal Welds

The nominal member buckling strength P_n of members with longitudinal welds is

$$P_n = P_{no}(1 - A_{wz}/A_g) + P_{nw}(A_{wz}/A_g) \qquad \text{(E.6-1)}$$

where

P_{no} = nominal member buckling strength if no part of the cross section were weld-affected. Use buckling constants for unwelded metal (Table B.4.1 or Table B.4.2) and mechanical properties from Table A.3.4 or Table A.3.4M.
P_{nw} = nominal member buckling strength if the entire cross section were weld-affected. Use buckling constants for weld-affected zones (Table B.4.1) and mechanical properties from Table A.3.5 or Table A.3.5M.

Chapter F Design of Members for Flexure

This chapter addresses members subjected to bending that are either

a) loaded in a plane parallel to a principal axis that passes through the shear center, or
b) restrained against rotation about their longitudinal axis at load points and supports.

F.1 General Provisions

The design flexural strength $\phi_b M_n$ and allowable flexural strength M_n/Ω_b shall be determined in accordance with Chapter F, where M_n = nominal flexural strength, and

Limit State	ϕ_b building-type structures	Ω_b building-type structures	Ω_b bridge-type structures
tensile rupture	0.75	1.95	2.20
other flexural limit states	0.90	1.65	1.85

Buckling constants are given in Tables B.4.1, B.4.2, and B.4.3. For weld-affected members see Section F.9.

F.1.1 Bending Coefficient C_b

a) Members supported on both ends: For members subjected to uniform bending moment, the bending coefficient $C_b = 1$. For other members, C_b shall be taken as 1 or determined in accordance with Section F.1.1.1 or F.1.1.2.
b) Cantilevers: C_b shall be determined in accordance with Section F.1.1.1.

F.1.1.1 Doubly Symmetric Shapes

For doubly symmetric shapes between brace points

$$C_b = \frac{12.5M_{\max}}{2.5M_{\max} + 3M_A + 4M_B + 3M_C} \qquad \text{(F.1-1)}$$

where

$M_{\max}$ = absolute value of the maximum moment in the unbraced segment
M_A = absolute value of the moment at the quarter point of the unbraced segment
M_B = absolute value of the moment at the midpoint of the unbraced segment
M_C = absolute value of the moment at the three-quarter point of the unbraced segment

For doubly symmetric shape cantilevers unbraced at the free end, C_b shall be determined as follows:

Loading	C_b
Concentrated load applied at the centroid at the free end	1.3
Uniform transverse load applied at the centroid	2.1

F.1.1.2 Singly Symmetric Shapes

For singly symmetric shapes between brace points

a) If $I_{cy}/I_y \leq 0.1$ or $I_{cy}/I_y \geq 0.9$, $C_b = 1.0$
b) If $0.1 < I_{cy}/I_y < 0.9$, C_b shall be determined using Equation F.1-1.

If $M_{\max}$ produces compression on the larger flange and the smaller flange is also subjected to compression in the unbraced length, the member shall be checked at the location of $M_{\max}$ using C_b determined using Equation F.1-1 and at the location where the smaller flange is subjected to its maximum compression using $C_b = 1.67$.

F.2 Open Shapes

For open shapes subject to lateral-torsional buckling, the nominal flexural strength shall be determined using Sections F.2.1, F.2.3, and F.8. For open shapes not subject to lateral-torsional buckling, the nominal flexural strength shall be determined using Section F.8. For single angles, the nominal flexural strength shall be determined using Section F.5.

F.2.1 Lateral-Torsional Buckling

For the limit state of lateral-torsional buckling, the nominal flexural strength is $M_n = F_b S_c$ where the lateral-torsional buckling stress F_b is:

Limit State	F_b	$\dfrac{L_b}{r_{ye}\sqrt{C_b}}$	Slenderness Limits
inelastic buckling	$B_c - \dfrac{D_c L_b}{1.2r_{ye}\sqrt{C_b}}$	$\dfrac{L_b}{r_{ye}\sqrt{C_b}} < S_2$	$S_2 = 1.2C_c$
elastic buckling	$\dfrac{\pi^2 E}{\left(\dfrac{L_b}{1.2r_{ye}\sqrt{C_b}}\right)^2}$	$\dfrac{L_b}{r_{ye}\sqrt{C_b}} \geq S_2$	

r_{ye} shall be r_y or determined from Section F.2.2.

F.2.2 Effective Radius of Gyration r_{ye}

F.2.2.1 Shapes Symmetric About the Bending Axis

For shapes symmetric about the bending axis:

a) Between brace points of beams subjected to end moment only or to transverse loads applied at the beam's neutral axis, or at brace points:

$$r_{ye} = \frac{1}{1.7}\sqrt{\frac{I_y d}{S_c}}\sqrt{1 + 0.152\frac{J}{I_y}\left(\frac{L_b}{d}\right)^2} \qquad \text{(F.2-1)}$$

b) Between brace points of beams subjected to transverse loads applied on the top or bottom flange (where the load is free to move laterally with the beam if the beam buckles):

$$r_{ye} = \frac{1}{1.7}\sqrt{\frac{I_y d}{S_c}\left[\pm 0.5 + \sqrt{1.25 + 0.152\frac{J}{I_y}\left(\frac{L_b}{d}\right)^2}\right]} \qquad \text{(F.2-2)}$$

0.5 is negative when the load acts toward the shear center and positive when the load acts away from the shear center.

where

The y-axis is the centroidal symmetry or principal axis that is parallel to the web.

I_y = moment of inertia about the y-axis
S_c = section modulus, compression side
d = depth of the beam

F.2.2.2 Singly Symmetric Shapes Unsymmetric about the Bending Axis

For singly symmetric shapes unsymmetric about the bending axis, calculate r_{ye} by either:

a) using Section F.2.2.1 with I_y, S_c and J determined as though both flanges were the same as the compression flange with the overall depth d remaining the same, or
b) using Section F.2.2.3.

F.2.2.3 Shapes Unsymmetric about the Bending Axis

For shapes unsymmetric about the bending axis and with:

a) braces on both ends, and
b) loading that does not cause torsion or lateral bending (if the loading causes torsion or lateral bending, apply Section H.3):

$$r_{ye} = \frac{L_b}{1.2\pi}\sqrt{\frac{M_e}{ES_c}} \qquad \text{(F.2-3)}$$

where

$$M_e = A_g F_{ey}\left[U + \sqrt{U^2 + r_o^2\left(\frac{F_{ez}}{F_{ey}}\right)}\right] \qquad \text{(F.2-4)}$$

The y-axis is the centroidal symmetry or principal axis such that the tension flange has a positive y coordinate and bending is about the x-axis. The origin of the coordinate system is the intersection of the principal axes.

$$F_{ey} = \frac{\pi^2 E}{\left(\frac{k_y L_b}{r_y}\right)^2} \qquad \text{(F.2-5)}$$

k_y = effective length factor for the compression flange about the y-axis. k_y shall not be less than 1.0.

$$U = C_1 g_0 - C_2 j \qquad \text{(F.2-6)}$$

C_1 and C_2: if the moment varies linearly between the ends of the unbraced segment $C_1 = 0$ and $C_2 = 1$. For simply supported singly symmetric shapes with $0.1 < I_{cy}/I_y < 0.9$:

a) For a uniformly distributed load over the entire span, $C_b = 1.13$, $C_1 = 0.41C_b$, and $C_2 = 0.47C_b$.
b) For a concentrated load at a distance aL from one end of the span,
   $C_b = 1.75 - 1.6a(1 - a)$
   $C_1 = C_b\sin^2\pi a/[a(1 - a)\pi^2]$
   $C_2 = (C_b - C_1)/2$
c) For two symmetric concentrated loads at a distance aL from each end of the span,
   $C_b = 1 + 2.8a^3$
   $C_1 = 2C_b\sin^2\pi a/(a\pi^2)$
   $C_2 = (1 - a)C_b - C_1/2$

g_0 = distance from the shear center to the point of application of the load; g_0 is positive when the load acts away from the shear center and negative when the load acts towards the shear center. If there is no transverse load (pure moment cases) $g_0 = 0$.

$$j = \frac{1}{2I_x}\left(\int_A y^3 dA + \int_A yx^2 dA\right) - y_0 \qquad \text{(F.2-7)}$$

For singly symmetric I shapes, as an alternative to Equation F.2-7,

$$j = 0.45d_f\left(\frac{2I_{cy}}{I_y} - 1\right)\left[1 - \left(\frac{I_y}{I_x}\right)^2\right] \qquad \text{(F.2-8)}$$

where

I_{cy} = moment of inertia of the compression flange about the y-axis
d_f = the distance between the flange centroids; for tees d_f is the distance between the flange centroid and the tip of the stem.

Alternately, for singly symmetric I shapes where the smaller flange area is not less than 80% of the larger flange area, j shall be taken as $-y_o$.

$$F_{ez} = \frac{1}{A_g r_o^2}\left(GJ + \frac{\pi^2 EC_w}{(k_z L_z)^2}\right) \qquad \text{(F.2-9)}$$

L_z = unbraced length for twisting
k_z = effective length factor for torsional buckling

$$r_o = \sqrt{r_x^2 + r_y^2 + x_o^2 + y_o^2} \qquad \text{(F.2-10)}$$

= polar radius of gyration of the cross section about the shear center
r_x, r_y = radii of gyration of the cross section about the centroidal principal axes
x_o = the shear center's x-coordinate
y_o = the shear center's y-coordinate

F.2.3 Interaction Between Local Buckling and Lateral-Torsional Buckling

For open shapes:

a) whose flanges are flat elements supported on one edge and

b) for which the flange's elastic buckling stress F_e given in Section B.5.6 is less than the lateral-torsional buckling stress of the beam F_b determined in accordance with Section F.2.1, the lateral-torsional buckling strength shall not exceed

$$M_n = \left[\frac{\pi^2 E}{\left(\frac{L_b}{1.2 r_{ye} \sqrt{C_b}} \right)^2} \right]^{1/3} F_e^{2/3} S_c \qquad \text{(F.2-11)}$$

F.3 Closed Shapes

The nominal flexural strength of pipes and round tubes shall be determined using Section F.6. For other closed shapes, the nominal flexural strength shall be determined using Section F.8. For other closed shapes subject to lateral-torsional buckling, the nominal flexural strength shall not exceed the value determined in Section F.3.1.

F.3.1 Lateral-Torsional Buckling

For the limit state of lateral-torsional buckling, the nominal flexural strength is $M_n = F_b S_c$ where the lateral-torsional buckling stress F_b is:

Limit State	F_b	$\frac{2L_bS_c}{C_b\sqrt{I_yJ}}$	Slenderness Limits
inelastic buckling	$B_c - 1.6D_c\sqrt{\frac{2L_bS_c}{C_b\sqrt{I_yJ}}}$	$\frac{2L_bS_c}{C_b\sqrt{I_yJ}} < S_2$	$S_2 = \left(\frac{C_c}{1.6}\right)^2$
elastic buckling	$\frac{\pi^2 E}{2.56\left(\frac{2L_bS_c}{C_b\sqrt{I_yJ}}\right)}$	$\frac{2L_bS_c}{C_b\sqrt{I_yJ}} \geq S_2$	

F.4 Rectangular Bars

The nominal flexural strength of rectangular bars shall be determined for the limit states of yielding and rupture in Section F.4.1 and lateral-torsional buckling in Section F.4.2.

F.4.1 Yielding and Rupture

For the limit state of compressive yielding the nominal flexural strength $M_n = 1.3\ F_{cy}\ S$.

For the limit state of tensile yielding the nominal flexural strength $M_n = 1.3\ F_{ty}\ S$.

For the limit state of tensile rupture, the nominal flexural strength $M_n = 1.42\ F_{tu}\ S/k_t$.

F.4.2 Lateral-Torsional Buckling

For the limit state of lateral-torsional buckling with major axis bending, the nominal flexural strength $M_n = F_b\ S$ where the lateral-torsional buckling stress F_b is:

Limit State	F_b	$\frac{d}{t}\sqrt{\frac{L_b}{C_bd}}$	Slenderness Limits
inelastic buckling	$B_{br} - 2.3D_{br}\frac{d}{t}\sqrt{\frac{L_b}{C_bd}}$	$\frac{d}{t}\sqrt{\frac{L_b}{C_bd}} < S_2$	$S_2 = C_{br}/2.3$
elastic buckling	$\frac{\pi^2 E}{5.29\left(\frac{d}{t}\right)^2\left(\frac{L_b}{C_bd}\right)}$	$\frac{d}{t}\sqrt{\frac{L_b}{C_bd}} \geq S_2$	

F.5 Single Angles

For single angles, the nominal flexural strength M_n shall be determined as follows.

a) For the limit state of local buckling:

  (1) If a leg tip is a point of maximum compression (Figure F.5.1):

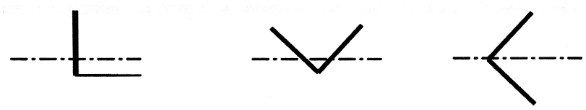


Figure F.5.1

for $b/t \leq S_1$, $M_n = 1.3F_{cy}S_c$ (F.5-1)

for $S_1 < b/t < S_2$, $M_n = [B_{br} - 4.0D_{br}(b/t)]S_c$ (F.5-2)

for $b/t \geq S_2$, $M_n = \pi^2ES_c/(4.0(b/t))^2$ (F.5-3)

where

$S_1 = (B_{br} - 1.3F_{cy})/(4.0D_{br})$ (F.5-4)

$S_2 = C_{br}/4.0$ (F.5-5)

  (2) If a leg is in uniform compression (Figure F.5.2):

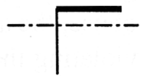


Figure F.5.2

for $b/t \leq S_1$, $M_n = F_{cy}S_c$ (F.5-6)

for $S_1 < b/t < S_2$, $M_n = [B_p - 5.0D_p(b/t)]S_c$ (F.5-7)

for $b/t \geq S_2$, $M_n = \pi^2ES_c/(5.0(b/t))^2$ (F.5-8)

where

$S_1 = (B_p - F_{cy})/(5.0D_p)$ (F.5-9)

$S_2 = C_p/5.0$ (F.5-10)

b) For the limit state of yielding (Figure F.5.3):

Figure F.5.3

$$M_n = 1.3M_y \qquad \text{(F.5-11)}$$

where M_y = yield moment about the axis of bending.

c) For the limit state of lateral-torsional buckling:

(1) for $M_e \le M_y$, $M_n = (0.92 - 0.17M_e/M_y)M_e$ (F.5-12)

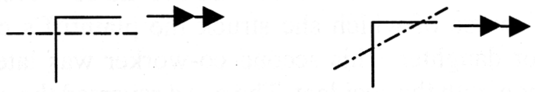
(2) for $M_e > M_y$, $M_n = (1.92 - 1.17\sqrt{M_y/M_e})M_y \le 1.3M_y$ (F.5-13)

where M_e = elastic lateral-torsional buckling moment from Section F.5.1 or F.5.2.

C_b between brace points shall be determined using Equation F.1-1 but shall not exceed 1.5.

F.5.1 Bending About Geometric Axes

Bending about a geometric axis is shown in Figure F.5.4. For combined axial compression and bending, resolve moments about principal axes and use Section F.5.2.



Subsections (a) and (b)

Subsection (c)

Figure F.5.4

a) *Angles with continuous lateral-torsional restraint:* M_n is the lesser of:
   (1) local buckling strength determined by Section F.5a.
   (2) yield strength determined by Section F.5b.

b) *Equal leg angles with lateral-torsional restraint only at the point of maximum moment:* Strengths shall be calculated with S_c being the geometric section modulus. M_n is the least of:
   (1) local buckling strength determined by Section F.5a.
   (2) yield strength determined by Section F.5b.
   (3) If the leg tip is in compression, lateral-torsional buckling strength determined by Section F.5c with

$$M_e = \frac{0.82Eb^4tC_b}{L_b^2}\left[\sqrt{1 + 0.78\left(L_b t/b^2\right)^2} - 1\right] \qquad \text{(F.5-14)}$$

If the leg tip is in tension, lateral-torsional buckling strength determined by Section F.5c with

$$M_e = \frac{0.82Eb^4tC_b}{L_b^2}\left[\sqrt{1 + 0.78\left(L_b t/b^2\right)^2} + 1\right] \qquad \text{(F.5-15)}$$

c) *Equal leg angles without lateral-torsional restraint:* Strengths shall be calculated with S_c equal to 0.80 of the geometric section modulus.
   If the leg tip is in compression, M_n is the lesser of:
   (1) local buckling strength determined by Section F.5a(1)
   (2) lateral-torsional buckling strength determined by F.5c with

$$M_e = \frac{0.66Eb^4tC_b}{L_b^2}\left[\sqrt{1 + 0.78\left(L_b t/b^2\right)^2} - 1\right] \qquad \text{(F.5-16)}$$

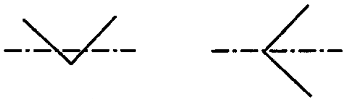
   If the leg tip is in tension, M_n is the lesser of:
   (1) yield strength determined by Section F.5b
   (2) lateral-torsional buckling strength determined by Section F.5c with

$$M_e = \frac{0.66Eb^4tC_b}{L_b^2}\left[\sqrt{1 + 0.78\left(L_b t/b^2\right)^2} + 1\right] \qquad \text{(F.5-17)}$$

d) *Unequal leg angles without lateral-torsional restraint:* moments about the geometric axes shall be resolved into moments about the principal axes and the angle shall be designed as an angle bent about a principal axis (Section F.5.2).

F.5.2 Bending About Principal Axes

Bending about principal axes is shown in Figure F.5.5.



Minor Axis Bending

Major Axis Bending

Figure F.5.5

a) *Equal leg angles, major axis bending:* M_n is the lesser of:
   (1) local buckling strength determined by Section F.5a
   (2) lateral-torsional buckling strength determined by Section F.5c, with

$$M_e = C_b\frac{0.46Eb^2t^2}{L_b} \qquad \text{(F.5-18)}$$

b) *Unequal leg angles, major axis bending:* M_n is the lesser of:
   (1) local buckling strength determined by Section F.5a for the leg with its tip in compression
   (2) lateral-torsional buckling strength determined by Section F.5c, with

$$M_e = 4.9E\frac{I_z}{L_b^2}C_b\left[\sqrt{\beta_w^2 + 0.052(L_b t/r_z)^2} + \beta_w\right] \qquad \text{(F.5-19)}$$

I_z = moment of inertia about the minor principal axis
r_z = radius of gyration about the minor principal axis

$$\beta_w = \left[\frac{1}{I_w}\int z\,(w^2 + z^2)dA\right] - 2z_o, \qquad \text{(F.5-20)}$$

β_w is a section property for unequal leg angles and is positive when the short leg is in compression and negative when the long leg is in compression. (See the commentary for values for common angle sizes and equations for determining β_w.) If the long leg is in compression anywhere along the unbraced length of the angle, β_w is negative.

z_o = coordinate along the z-axis of the shear center with respect to the centroid
I_w = moment of inertia about the major principal axis

c) *Equal and unequal leg angles, minor axis bending:*
   (1) If the leg tips are in compression, M_n is the lesser of the local buckling strength determined by Section F.5a(1) and the yield strength determined by Section F.5b.
   (2) If the leg tips are in tension, M_n is the yield strength determined by Section F.5b.

F.6 Pipes and Round Tubes

The nominal flexural strength of pipes and round tubes shall be determined for the limit states of yielding and rupture in Section F.6.1 and local buckling in Section F.6.2.

F.6.1 Yielding and Rupture

For the limit state of compressive yielding the nominal flexural strength $M_n = 1.17\ F_{cy}\ S$.

For the limit state of tensile yielding the nominal flexural strength $M_n = 1.17\ F_{ty}\ S$.

For the limit state of tensile rupture the nominal flexural strength $M_n = 1.24\ F_{tu}\ S/k_t$.

F.6.2 Local Buckling

For the limit state of local buckling, the nominal flexural strength $M_n = F_b\ S$ where the local buckling stress F_b is:

Limit State	F_b	$\frac{R_b}{t}$	Slenderness Limits
upper inelastic buckling	$B_{tb} - D_{tb}\sqrt{\frac{R_b}{t}}$	$\frac{R_b}{t} \le S_1$	$S_1 = \left(\frac{B_{tb} - B_t}{D_{tb} - D_t}\right)^2$
lower inelastic buckling	$B_t - D_t\sqrt{\frac{R_b}{t}}$	$S_1 < \frac{R_b}{t} < S_2$	
elastic buckling	$\dfrac{\pi^2 E}{16\left(\frac{R_b}{t}\right)\left(1 + \frac{\sqrt{R_b/t}}{35}\right)^2}$	$\frac{R_b}{t} \ge S_2$	$S_2 = C_t$

F.7 Rods

For rods, the nominal flexural strength shall be determined for the limit states of yielding and tensile rupture.

For the limit state of yielding, the nominal flexural strength M_n is the lesser of $1.3F_{ty}\ S$ and $1.3F_{cy}\ S$.

For the limit state of tensile rupture, the nominal flexural strength $M_n = 1.42F_{tu}\ S\ /k_t$.

F.8 Elements of Flexural Members

The nominal flexural strength of the elements of flexural members is the least of the strengths for tensile yielding and tensile rupture or for compression yielding and local buckling. Alternately, the nominal flexural strength of the elements of flexural members shall be determined as the weighted average flexural strength using Section F.8.3.

For the limit states of yielding and tensile rupture, the nominal flexural strength is $M_n = F_b\ S_t$ where F_b is determined using Section F.8.1.

For the limit state of compression, the nominal flexural strength is $M_n = F_b\ S_c$ where F_b is determined using Section F.8.2.

F.8.1 Tension

F.8.1.1 Elements in Uniform Tension

For the limit state of tensile yielding, the flexural tensile stress corresponding to the nominal flexural strength is:

For unwelded elements: $F_t = F_{ty}$
For transversely welded elements: $F_t = F_{tyw}$
For longitudinally welded elements:
$F_t = F_{ty}(1 - A_{wz}/A_g) + F_{tyw}\ A_{wz}/A_g$

For the limit state of tensile rupture, the flexural tensile stress corresponding to the nominal flexural strength is:

For unwelded elements: $F_t = F_{tu}/k_t$
For transversely welded elements: $F_t = F_{tuw}$
For longitudinally welded elements:
$F_t = F_{tu}(1 - A_{wz}/A_g)/k_t + F_{tuw}\ A_{wz}/A_g$.

F.8.1.2 Elements in Flexure

For the limit state of tensile yielding, the flexural tensile stress corresponding to the nominal flexural strength is:

For unwelded elements: $F_b = 1.30\ F_{ty}$
For transversely welded elements: $F_b = 1.30\ F_{tyw}$
For longitudinally welded elements:
$F_b = 1.30[F_{ty}(1 - A_{wzt}/A_{gt}) + F_{tyw}\ A_{wzt}/A_{gt}]$

For the limit state of tensile rupture, the flexural tensile stress corresponding to the nominal flexural strength is:

For unwelded elements: $F_b = 1.42F_{tu}/k_t$
For transversely welded elements: $F_b = 1.42F_{tuw}$
For longitudinally welded elements:
$F_b = 1.42[F_{tu}(1 - A_{wzt}/A_{gt})/k_t + F_{tuw}\ A_{wzt}/A_{gt}]$

F.8.2 Compression

For elements in compression, the flexural compressive stress corresponding to the nominal flexural strength F_b is given in Sections F.8.2.1 and F.8.2.2. Alternately, the compressive strength of elements of beams composed of flat elements may be determined using Section F.8.2.3.

F.8.2.1 Elements in Uniform Compression

For beam elements in uniform compression, the flexural compressive strength is given in Section B.5.4.

F.8.2.2 Elements in Flexure

For beam elements in flexure, the flexural compressive strength is given in Section B.5.5.

F.8.2.3 Alternate Compressive Flexural Strength

As an alternate to Sections F.8.2.1 and F.8.2.2, the compressive strength of elements of beams composed of flat elements without welds may be determined as follows:

The flexural compressive stress F_c corresponding to the nominal flexural strength for the shape's flat elements in uniform compression shall be determined in accordance with Section B.5.4.6.

The flexural compressive stress F_b corresponding to the nominal flexural strength for the shape's flat elements in flexure shall be determined in accordance with Section B.5.5.4.

F.8.3 Weighted Average Flexural Strength

The weighted average nominal flexural strength M_n is the lesser of

a) the compressive flexural strength

$$M_{nc} = F_c I_f / c_{cf} + F_b I_w / c_{cw} \qquad \text{(F.8-1)}$$

where (see Figure F.8.1)

F_c = local buckling stress of the flat elements in uniform compression determined using Section F.8.2.1 or F.8.2.3. The strength of stiffened elements shall not exceed the strength of an intermediate stiffener or an edge stiffener.

F_b = local buckling stress of the flat elements in flexure determined using Section F.8.2.2 or F.8.2.3.

c_{cf} = distance from the centerline of the compression flange to the cross section's neutral axis

c_{cw} = distance from the web group's extreme compression fiber to the cross section's neutral axis

I_f = moment of inertia of the flange group about the cross section's neutral axis. The flange group consists of the flat elements in uniform compression and the flat elements in uniform tension and their edge or intermediate stiffeners.

I_w = moment of inertia of the web group about the cross section's neutral axis. The web group consists of the flat elements in flexure and their intermediate stiffeners.

If there are stiffeners located farther than the compression flange from the cross section's neutral axis, the compressive flexural strength shall not exceed

$$F_{cy} I_f / c_{cs} + F_b I_w / c_{cw}$$

where

c_{cs} = distance from the cross section's neutral axis to the extreme fiber of compression flange stiffeners

and

b) the tensile flexural strength

$$M_{nt} = F_t I_f / c_{tf} + F_b I_w / c_{tw} \qquad \text{(F.8-2)}$$

where (see Figure F.8.1)

F_t = tensile stress for the flat elements in uniform tension determined using Section F.8.1.1

F_b = tensile stress for the flat elements in flexure determined using Section F.8.1.2

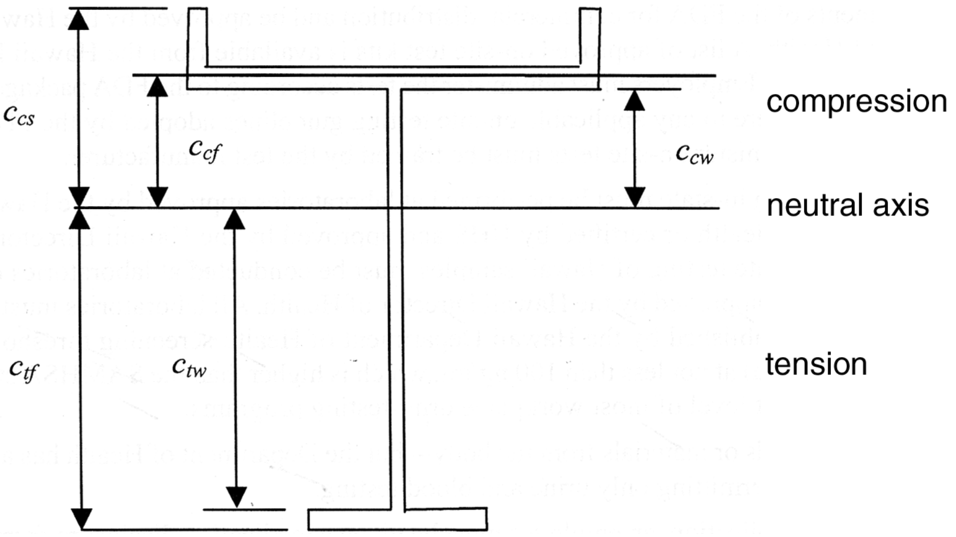


Figure F.8.1

c_{tf} = distance from the extreme tension fiber to the cross section's neutral axis

c_{tw} = distance from the web group's extreme tension fiber to the cross section's neutral axis

F.9 Welded Flexural Members

F.9.1 Flexural Members with Transverse Welds

The lateral-torsional buckling strength of members supported at both ends with no transverse weld farther than $0.05L$ from the member ends shall be calculated as if there were no welds.

The lateral-torsional buckling strength of members supported at both ends with a transverse weld farther than $0.05L$ from the member ends and members supported at only one end with a transverse weld at any location shall be calculated as if the entire cross-sectional area were weld-affected.

For tubes with circumferential welds, Section B.5.4.5 only applies if $R_b/t \leq 20$.

F.9.2 Flexural Members with Longitudinal Welds

The lateral-torsional buckling strength M_n of members with longitudinal welds is

$$M_n = M_{no}(1 - A_{wz}/A_f) + M_{nw}(A_{wz}/A_f) \qquad \text{(F.9-1)}$$

where

M_{no} = lateral-torsional buckling strength if no part of the cross section were weld-affected. Use buckling constants for unwelded metal (Table B.4.1 or Table B.4.2) and mechanical properties from Table A.3.4 or Table A.3.4M.

M_{nw} = lateral-torsional buckling strength if the entire cross section were weld-affected. Use buckling constants for weld-affected zones (Table B.4.1) and mechanical properties from Table A.3.5 or Table A.3.5M.

A_f = area of the member farther than $2c/3$ from the neutral axis, where c is the distance from the neutral axis to the extreme compression fiber.

Chapter G Design of Members for Shear

This chapter addresses flat webs of members subjected to shear in the plane of the web and shear in round and oval tubes.

G.1 General Provisions

The design shear strength $\phi_v V_n$ and the allowable shear strength V_n/Ω_v shall be determined from Section G.2 or G.3, where

$\phi_v = 0.90$ (LRFD)
$\Omega_v = 1.65$ (ASD building-type structures)
$\Omega_v = 1.85$ (ASD bridge-type structures)

The shear stress corresponding to the shear strength is

For unwelded members:

$$F_s = F_{so} \tag{G.1-1}$$

For welded members:

$$F_s = F_{so}(1 - A_{wz}/A_g) + F_{sw}\,A_{wz}/A_g \tag{G.1-2}$$

where

F_{so} = shear stress corresponding to the shear strength for an element if no part of the cross section were weld-affected. Use buckling constants for unwelded metal (Table B.4.1 or Table B.4.2) and mechanical properties from Table A.3.4 or Table A.3.4M.
F_{sw} = shear stress corresponding to the shear strength for an element if the entire cross section were weld-affected. Use buckling constants for weld-affected zones (Table B.4.1) and mechanical properties from Table A.3.5 or Table A.3.5M. For transversely welded elements with $b/t \le S_1$, $F_s = F_{so}$.
A_{wz} = cross sectional area of the weld-affected zone
A_g = gross cross sectional area of the element.

The shear stress F_s corresponding to the nominal shear strength in weld-affected zones shall not exceed $F_{suw}/1.2$.

G.2 Members with Flat Webs Supported on Both Edges

The nominal shear strength V_n of flat webs supported on both edges is

$$V_n = F_s\,A_w \tag{G.2-1}$$

The shear stress F_s corresponding to the shear strength is

Limit State	F_s	b/t	Slenderness Limits
yielding	F_{sy}	$b/t \le S_1$	$S_1 = \dfrac{B_s - F_{sy}}{1.25D_s}$
inelastic buckling	$B_s - 1.25D_s\,b/t$	$S_1 < b/t < S_2$	
elastic buckling	$\dfrac{\pi^2 E}{(1.25b/t)^2}$	$b/t \ge S_2$	$S_2 = \dfrac{C_s}{1.25}$

where

b = clear height of the web (see Figure G.2.1) for unstiffened webs and
$b = \dfrac{a_1}{\sqrt{1 + 0.7\left(\dfrac{a_1}{a_2}\right)^2}}$ for webs with transverse stiffeners
a_1 = the lesser of the clear height of the web and the distance between stiffeners
a_2 = the greater of the clear height of the web and the distance between stiffeners
t = web thickness
$A_w = dt$
d = full depth of the section

Transverse stiffeners shall have a moment of inertia I_s not less than the following:

$$\frac{s}{b} \le 0.4, \qquad I_s = \frac{0.55Vb^2}{E}\left(\frac{s}{b}\right) \tag{G.2-2}$$

$$\frac{s}{b} > 0.4, \qquad I_s = \frac{0.088Vb^2}{E}\left(\frac{b}{s}\right) \tag{G.2-3}$$

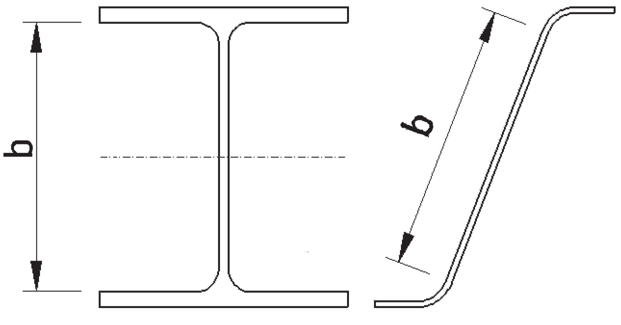


Figure G.2.1
FLAT WEBS IN SHEAR

where

b = clear height of the web regardless of whether or not a longitudinal stiffener is present

I_s = moment of inertia of the transverse stiffener. For a stiffener composed of members of equal size on each side of the web, the moment of inertia of the stiffener shall be computed about the centerline of the web. For a stiffener composed of a member on only one side of the web, the moment of inertia of the stiffener shall be computed about the face of the web in contact with the stiffener.

s = transverse stiffener spacing. For a stiffener composed of a pair of members, one on each side of the web, the stiffener spacing s is the clear distance between the pairs of stiffeners. For a stiffener composed of a member on only one side of the web, the stiffener spacing s is the distance between fastener lines or other connecting lines.

V = shear force on the web at the transverse stiffener

Stiffeners shall extend from flange to flange but need not be connected to either flange. Unless the outer edge of a stiffener is continuously stiffened, its thickness shall not be less than 1/12th the clear width of the outstanding leg.

G.3 Round or Oval Tubes

The nominal shear strength V_n of round or oval tubes is

$$V_n = F_s A_g/2 \tag{G.3-1}$$

where:

Limit State	F_s	λ_t	Slenderness Limits
yielding	F_{sy}	$\lambda_t \le S_1$	$S_1 = \frac{1.3B_s - F_{sy}}{1.63D_s}$
inelastic buckling	$1.3B_s - 1.63D_s\,\lambda_t$	$S_1 < \lambda_t < S_2$	
elastic buckling	$\frac{1.3\pi^2 E}{(1.25\,\lambda_t)^2}$	$\lambda_t \ge S_2$	$S_2 = \frac{C_s}{1.25}$

$$\lambda_t = 2.9\left(\frac{R_b}{t}\right)^{5/8}\left(\frac{L_v}{R_b}\right)^{1/4} \tag{G.3-2}$$

R_b = mid-thickness radius of a round tube or maximum mid-thickness radius of an oval tube

t = thickness of tube

L_v = length of tube from maximum to zero shear force.

Chapter H Design of Members for Combined Forces and Torsion

This chapter addresses members subject to axial force and flexure about one or both axes, with or without torsion, and to members subject to torsion only.

H.1 Members Subject to Flexure and Axial Force

For members subject to flexure and axial force,

$$\left|\frac{P_r}{P_c}+\frac{M_{rx}}{M_{cx}}+\frac{M_{ry}}{M_{cy}}\right| \le 1.0 \tag{H.1-1}$$

where:

x = subscript for major principal axis bending
y = subscript for minor principal axis bending

For LRFD:

P_r = required axial force using LRFD load combinations
For axial tension:
P_c = design axial tensile strength determined in accordance with Chapter D
For axial compression:
P_c = design axial compressive strength determined in accordance with Chapter E
M_r = required flexural strength using LRFD load combinations
M_c = design flexural strength determined in accordance with Chapter F

For ASD:

P_r = required axial force using ASD load combinations
For axial tension:
P_c = allowable axial tensile strength determined in accordance with Chapter D
For axial compression:
P_c = allowable axial compressive strength determined in accordance with Chapter E
M_r = required flexural strength using ASD load combinations
M_c = allowable flexural strength determined in accordance with Chapter F

H.2 Members Subject to Torsion

The design torsional strength $\phi_T T_n$ and the allowable torsional strength T_n/Ω_T shall be determined in accordance with Section H.2, where

$\phi_T = 0.90$ (LRFD)
$\Omega_T = 1.65$ (ASD building-type structures)
$\Omega_T = 1.85$ (ASD bridge-type structures)

H.2.1 Round or Oval Tubes

The nominal torsional strength T_n for round or oval tubes for the limit state of torsional yielding and torsional buckling is

$$T_n = F_s J/R \tag{H.2-1}$$

where

Limit State	F_s	λ_t	Slenderness Limits
yielding	F_{sy}	$\lambda_t \le S_1$	$S_1 = \dfrac{B_s - F_{sy}}{1.25D_s}$
inelastic buckling	$B_s - 1.25D_s\,\lambda_t$	$S_1 < \lambda_t < S_2$	
elastic buckling	$\dfrac{\pi^2 E}{(1.25\lambda_t)^2}$	$\lambda_t \ge S_2$	$S_2 = \dfrac{C_s}{1.25}$

$$\lambda_t = 2.9\left(\frac{R_b}{t}\right)^{5/8}\left(\frac{L_s}{R_b}\right)^{1/4} \tag{H.2-2}$$

R_b = mid-thickness radius of a round tube or the maximum mid-thickness radius of an oval tube
t = tube thickness
L_s = length of tube between circumferential stiffeners, or overall length if no circumferential stiffeners are present
R = outside radius of the tube
J = torsion constant of the tube

H.2.2 Rectangular Tubes

The nominal torsional strength T_n for rectangular tubes for the limit state of torsional yielding and torsional buckling is

$$T_n = F_s C \tag{H.2-3}$$

where F_s is determined in accordance with Section G.2 for the side with the larger slenderness and C is the torsional shear constant.

H.2.3 Rods

The nominal torsional strength T_n for rods for the limit state of torsional yielding is

$$T_n = 0.196 F_{sy} D^3 \tag{H.2-4}$$

where

D = diameter of the rod

H.3 Members Subject to Torsion, Flexure, Shear, and/or Axial Compression

H.3.1 Flat Elements

Stresses in flat elements subject to torsion, flexure, shear, and/or axial compression shall satisfy the following:

For LRFD:

$$f_c/(\phi F_c) + [f_b/(\phi F_b)]^2 + [f_s/(\phi F_s)]^2 \le 1.0 \tag{H.3-1}$$

For ASD:

$$f_c/(F_c/\Omega) + [f_b/(F_b/\Omega)]^2 + [f_s/(F_s/\Omega)]^2 \le 1.0 \qquad \text{(H.3-2)}$$

where

f_c = uniform compressive stress due to axial compression
f_b = compressive stress due to flexure
f_s = shear stress due to shear and torsion
F_c = axial compression stress corresponding to the nominal axial compression strength
F_b = bending stress corresponding to the nominal flexural compression strength
F_s = shear stress corresponding to the nominal shear strength

H.3.2 Curved Elements

Stresses in curved elements subject to torsion, flexure, shear, and/or axial compression shall satisfy the following:

For LRFD:

$$f_c/(\phi F_c) + f_b/(\phi F_b) + [f_s/(\phi F_s)]^2 \le 1.0 \qquad \text{(H.3-3)}$$

For ASD:

$$f_c/(F_c/\Omega) + f_b/(F_b/\Omega) + [f_s/(F_s/\Omega)]^2 \le 1.0 \qquad \text{(H.3-4)}$$

where

f_c = compressive stress due to axial compression
f_b = compressive stress due to flexure
f_s = shear stress due to shear and torsion
F_c = axial compression stress corresponding to the nominal axial compression strength
F_b = bending stress corresponding to the nominal flexural compression strength
F_s = shear stress corresponding to the nominal shear strength

Chapter J Design of Connections

This chapter addresses connecting elements and connectors.

J.1 General Provisions

J.1.1 Design Basis

The design strength and the allowable strength of connections shall be determined in accordance with the provisions of this chapter and Chapter B.

If the longitudinal centroidal axes of connected axially loaded members do not intersect at one point, the connection and members shall be designed for the effects of eccentricity.

J.1.2 Fasteners in Combination with Welds

Fasteners shall not be considered to share load in combination with welds.

J.1.3 Maximum Spacing of Fasteners

The pitch and gage of fasteners joining components of tension members shall not exceed $(3 + 20t)$ in. $[(75 + 20t)$ mm] where t is the thickness of the outside component.

In outside components of compression members:

a) The component's strength shall satisfy the requirements of Section E.3 with an effective length $kL = s/2$, where s is the pitch, and
b) If multiple rows of fasteners are used, the component's strength shall satisfy the requirements of Section B.5.4.2 with a width $b = 0.8g$ where g is the gage. If only one line of fasteners is used, the component's strength shall satisfy the requirements of Section B.5.4.1 with a width b = the edge distance of the fastener.

J.2 Welds

The design strength ϕR_n and allowable strength R_n/Ω of welds shall be determined from Sections J.2.1 through J.2.4 where

$\phi = 0.75$ (LRFD)
$\Omega = 1.95$ (ASD building-type structures)
$\Omega = 2.20$ (ASD bridge-type structures)

J.2.1 Groove Welds

J.2.1.1 Complete Penetration and Partial Penetration Groove Welds

The following types of groove welds are complete penetration welds:

a) Welds welded from both sides with the root of the first weld backgouged to sound metal before welding the second side.
b) Welds welded from one side using permanent or temporary backing.
c) Welds welded from one side using AC-GTAW root pass without backing
d) Welds welded from one side using PAW-VP in the keyhole mode.

All other groove welds are partial penetration welds.

J.2.1.2 Effective Area

a) Size: The size S_w of a complete joint penetration groove weld is the thickness of the thinner part joined. The size S_w of a partial joint penetration groove weld is the depth of preparation (see Figure J.2.1) for all V and bevel groove welds with an included angle greater than 45°, and the depth of preparation of all J and U groove welds.
b) Length: The effective weld length L_{we} for tension and compression is the length of the weld perpendicular to the direction of tensile or compressive stress. The effective weld length for shear is the length of the weld parallel to the direction of shear stress.
c) Area: The effective area A_{we} of a groove weld is the effective weld length times the weld size.

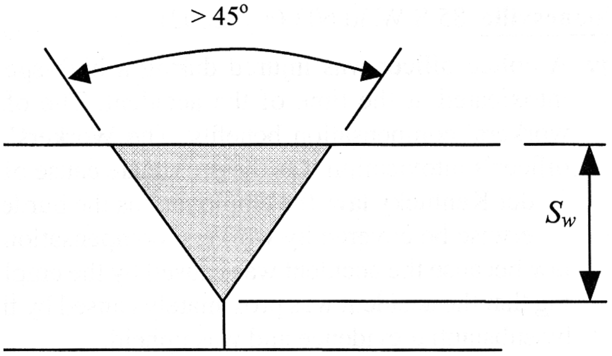


Figure J.2.1
PARTIAL JOINT PENETRATION GROOVE WELD

J.2.1.3 Strength

The nominal tensile or compressive strength R_n of a groove weld is:

$$R_n = F_{tuw} A_{we} \qquad \text{(J.2-1)}$$

where

F_{tuw} = least of the welded tensile ultimate strengths of the base metals and the filler. Welded tensile ultimate strengths of base metals shall be taken from Table A.3.5 or Table A.3.5M and tensile ultimate strengths of fillers from Table J.2.1 or Table J.2.1M.

A_{we} = weld effective area

The nominal shear strength R_n of a groove weld is:

$$R_n = F_{suw} A_{we} \quad \text{(J.2-2)}$$

where

F_{suw} = least of the welded shear ultimate strengths of the base metals and the filler. Welded shear ultimate strengths of base metals shall be taken from Table A.3.5 or Table A.3.5M and shear ultimate strengths of fillers from Table J.2.1 or Table J.2.1M

A_{we} = weld effective area.

J.2.2 Fillet Welds

J.2.2.1 Effective Throat and Effective Length

a) The effective throat is the shortest distance from the joint root to the face of the diagrammatic weld (see Figure J.2.2).

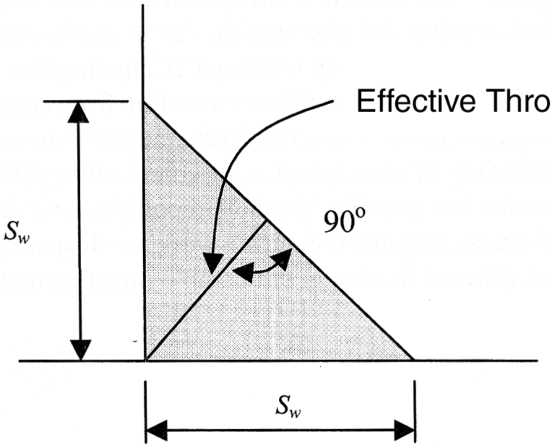


Figure J.2.2
EFFECTIVE THROAT OF A FILLET WELD

b) The weld effective length L_{we} is the overall length of the weld, including boxing. If the effective length of a fillet weld is less than 4 times its nominal size S_w (see Figure J.2.2), the effective weld size shall be considered to be 25% of its effective length.

The minimum length of segments of an intermittent fillet weld shall be 1½ in. (40 mm). The maximum effective length of an end-loaded fillet weld is $100S_w$.

J.2.2.2 Strength

Stress on a fillet weld shall be considered to be shear for any direction of applied load. The nominal shear strength R_n of a fillet weld is:

$$R_n = F_{sw} L_{we} \quad \text{(J.2-3)}$$

where

F_{sw} = least of:

a) the product of the weld filler's shear ultimate strength and the effective throat.
b) for base metal in shear at the weld-base metal joint, the product of the base metal's welded shear ultimate strength and the fillet size S_w at the joint;
c) for base metal in tension at the weld-base metal joint, the product of the base metal's welded tensile ultimate strength and the fillet size S_w at the joint.

Welded shear and tensile ultimate strengths of base metals shall be taken from Table A.3.5 or Table A.3.5M and shear ultimate strengths of weld fillers from Table J.2.1 or Table J.2.1M.

L_{we} = weld effective length

J.2.3 Plug and Slot Welds

J.2.3.1 Effective Area

The effective area A_{we} of plug or slot welds is the nominal area of the hole or slot in the plane of the faying surface (see Figure J.2.3). Slot lengths shall not exceed 10 times the slotted material's thickness.

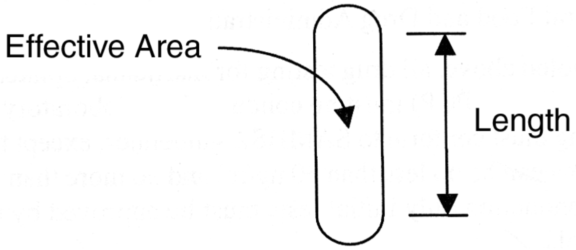


Figure J.2.3
SLOT WELD PLAN VIEW

J.2.3.2 Strength

The nominal shear strength R_n of a plug or slot weld is:

$$R_n = F_{sw} A_{we} \quad \text{(J.2-4)}$$

where

F_{sw} = lesser of the welded shear ultimate strengths of the filler and the base metal under the weld. Welded shear ultimate strengths of base metals shall be taken from Table A.3.5 or Table A.3.5M and shear ultimate strengths of fillers from Table J.2.1 or Table J.2.1M.

A_{we} = weld effective area

Table J.2.1
FILLER STRENGTHS

Filler	Tensile Ultimate Strength (ksi)	Shear Ultimate Strength (ksi)
1100	11	7.5
2319	35	16
4043	24	11.5
4047	–	13
4643	–	13.5
5183	40	21
5356	35	17
5554	31	17
5556	42	20
5654	30	12

Table J.2.1M
FILLER STRENGTHS

Filler	Tensile Ultimate Strength (MPa)	Shear Ultimate Strength (MPa)
1100	75	50
2319	240	110
4043	165	80
4047	–	90
4643	–	95
5183	275	145
5356	240	115
5554	215	115
5556	290	140
5654	205	85

J.2.4 Stud Welds

The nominal tensile strength R_n of a stud weld is:

$$R_n = T_{uw} \qquad \text{(J.2-5)}$$

where

T_{uw} = tensile strength of the stud in Table J.2.2 or Table J.2.2M

The base metal thickness for arc stud welding shall not be less than 50% of the stud diameter. The base metal thickness for capacitor discharge stud welding shall not be less than 25% of the stud diameter.

J.2.5 Post-Weld Heat Treating

For 6005 lighting poles through 0.250 in. (6 mm) thick welded in the T1 temper with 4043 filler and artificially aged to the T5 temper after welding, design and allowable stresses of the base metal within 1.0 in. (25 mm) of the weld shall be 85% of the values for unwelded 6005-T5.

Table J.2.2
TENSILE STRENGTHS FOR 5183, 5356, AND 5556 STUDS

Stud Size	Arc (lb)	Capacitor Discharge (lb)
6–32	–	375
8–32	–	635
10–24	770	770
¼–20	1360	1360
5⁄16–18	2300	2300
3⁄8–16	3250	–
7⁄16–14	4400	–
½–13	5950	–

Table J.2.2M
TENSILE STRENGTHS FOR 5183, 5356, AND 5556 STUDS

Stud Size	Arc (kN)	Capacitor Discharge (kN)
6–32	–	1.67
8–32	–	2.82
10–24	3.42	3.42
¼–20	6.05	6.05
5⁄16–18	10.2	10.2
3⁄8–16	14.5	–
7⁄16–14	19.6	–
½–13	26.5	–

For 6063 lighting poles through 0.375 in. (10 mm) thick welded in the T4 temper with 4043 filler and artificially aged to the T6 temper after welding:

a) The design and allowable stresses of the base metal within 1.0 in. (25 mm) of the weld shall be 85% of the values for unwelded 6063-T6.
b) The design stress is 12.5 ksi (85 MPa) and the allowable stress is 8 ksi (55 MPa) for welds in socket type bases.
c) The design stress is 9 ksi (60 MPa) and the allowable stress is 5.9 ksi (41 MPa) for welds in other than socket type bases.

J.3 Bolts

J.3.1 Bolt Material

Bolt material shall be:

a) Aluminum: Bolts shall meet ASTM F 468 and be 2024-T4, 6061-T6, or 7075-T73. When 2024 bolts will be exposed to contact with liquid water or humidity near the dew point in the intended service, they shall have a minimum 0.0002 in. (0.005 mm) thick anodic coating. Nuts shall meet ASTM F 467. Nuts for ¼ in. (M6) bolts and smaller shall be 2024-T4; larger nuts shall be 6061-T6 or 6262-T9. Flat washers shall be Alclad 2024-T4. Spring lock washers shall be 7075-T6.

b) Carbon steel: Carbon steel bolts, nuts, and washers shall have a hot-dip zinc coating meeting ASTM A 153 or a mechanically deposited zinc coating meeting ASTM B 695 and shall be lubricated in accordance with ASTM A 563. The zinc coating thickness shall be adequate to provide corrosion protection for the anticipated service. If other coatings are used, their thickness shall be sufficient to provide corrosion protection for the intended service. Bolt hardness shall be less than Rockwell C35. A 490 bolts shall not be used.

c) Stainless steel: Stainless steel bolts, nuts and washers shall be 300 series. Bolts shall meet ASTM F 593, A 193, or A 320. Nuts shall meet ASTM F 594 or A 194.

J.3.2 Holes and Slots for Bolts

The nominal diameter of holes for bolts shall not be more than 1⁄16 in. (2 mm) greater than the nominal diameter of the bolt unless slip-critical connections are used.

The nominal width of slots for bolts shall not be more than 1⁄16 in. (2 mm) greater than the nominal diameter of the bolt. If the nominal length of the slot exceeds 2.5D or the edge distance is less than 2D, where D is the nominal bolt diameter, the edge distance perpendicular to the slot length and slot length shall be sized to avoid overstressing the material along the slot. Unless slip-critical connections are used, the length shall be perpendicular to the direction of force.

J.3.3 Minimum Spacing of Bolts

The distance between bolt centers shall not be less than 2.5 times the nominal diameter of the bolt.

J.3.4 Minimum Edge Distance of Bolts

The distance from the center of a bolt to an edge of a part shall not be less than 1.5 times the nominal diameter of the bolt. See Section J.3.7 for the effect of edge distance on bearing strength.

J.3.5 Bolt Tension

For aluminum bolts, the design tension strength ϕR_n and the allowable tension strength R_n/Ω shall be determined for the limit state of tensile rupture as follows:

$\phi = 0.65$ (LRFD)
$\Omega = 2.34$ (ASD building-type structures)
$\Omega = 2.64$ (ASD bridge-type structures)

$$R_n = (\pi(D - 1.191/n)^2/4)F_{tu} \qquad \text{(J.3-1)}$$

where

F_{tu} = tensile ultimate strength of the bolt (Table A.3.8 or Table A.3.8M).

J.3.6 Bolt Shear

For aluminum bolts, the design shear strength ϕR_n and the allowable shear strength R_n/Ω shall be determined for the limit state of shear rupture as follows:

$\phi = 0.65$ (LRFD)
$\Omega = 2.34$ (ASD building-type structures)
$\Omega = 2.64$ (ASD bridge-type structures)

a) For bolts with threads in the shear plane,

$$R_n = (\pi(D - 1.191/n)^2/4)F_{su} \qquad \text{(J.3-2)}$$

b) For bolts without threads in the shear plane,

$$R_n = (\pi D^2/4)F_{su} \qquad \text{(J.3-3)}$$

where

F_{su} = shear ultimate strength of the bolt (Table A.3.8 or Table A.3.8M).

J.3.7 Bolt Bearing

The design bearing strength ϕR_n and the allowable bearing strength R_n/Ω shall be determined for the limit state of bearing as follows:

$\phi = 0.75$ (LRFD)
$\Omega = 1.95$ (ASD building-type structures)
$\Omega = 2.20$ (ASD bridge-type structures)

a) For a bolt in a hole,

$$R_n = d_e t F_{tu} \le 2DtF_{tu} \qquad \text{(J.3-4)}$$

b) For a bolt in a slot with the slot perpendicular to the direction of force:

$$R_n = 1.33\, DtF_{tu} \qquad \text{(J.3-5)}$$

and the edge distance perpendicular to the slot length and slot length shall be sized to avoid overstressing the material between the slot and the edge of the part.

where

d_e = distance from the center of the bolt to the edge of the part in the direction of force.
t = for plain holes, thickness of the connected part; for countersunk holes, thickness of the connected part less ½ the countersink depth
F_{tu} = tensile ultimate strength of the connected part
D = nominal diameter of the bolt

J.3.8 Slip-Critical Bolted Connections

J.3.8.1 General

Slip-critical connections between aluminum members or between aluminum and steel members shall comply with the Research Council on Structural Connections (RCSC) *Specification for Structural Joints Using ASTM A325 or A490 Bolts* except as modified here. Slip-critical connections shall be designed for the limit states of shear rupture in accordance with Section J.3.8.4, bearing strength in accordance with Section J.3.7, and slip in accordance with Section J.3.8.5.

J.3.8.2 Material

Aluminum used in slip-critical connections shall have a tensile yield strength of at least 15 ksi (105 MPa). Bolts shall comply with ASTM A 325, nuts shall comply with ASTM A 563 Grade DH or ASTM A 194 Grade 2H, and washers shall comply with ASTM F 436. Bolts, nuts, and washers shall be zinc coated by the hot-dip or mechanically deposited processes as specified in ASTM A 325.

J.3.8.3 Holes

Holes shall be standard holes, oversize holes, short slotted holes, or long slotted holes. The nominal dimensions for each hole type shall not exceed those shown in the RCSC specification.

J.3.8.4 Design for Strength

The design shear strength ϕR_n and the allowable shear strength R_n/Ω shall be determined for the limit state of shear rupture as follows:

$\phi = 0.75$ (LRFD)
$\Omega = 2.0$ (ASD building-type structures)
$\Omega = 2.24$ (ASD bridge-type structures)

$$R_n = F_n A_b \qquad \text{(J.3-6)}$$

where

F_n = 48 ksi (330 MPa) for bolts with threads in the shear plane
F_n = 60 ksi (414 MPa) for bolts without threads in the shear plane
A_b = nominal cross sectional area (unthreaded body area) of the bolt

J.3.8.5 Design for Slip Resistance

Slip-critical connections shall be designed for the limit state of slip as follows:

a) connections with standard holes or slots transverse to the direction of the load shall be designed to prevent slip as a serviceability limit state.
b) connections with oversized holes or slots parallel to the direction of the load shall be designed to prevent slip as a strength limit state.

The design slip resistance ϕR_n and the allowable slip resistance R_n/Ω shall be determined for the limit state of slip as follows:

$$R_n = 1.13\mu h_{sc} T_b N_s \qquad \text{(J.3-7)}$$

For connections in which slip prevention is a serviceability limit state

$\phi = 1.00$ (LRFD)
$\Omega = 1.50$ (ASD building-type structures)
$\Omega = 1.68$ (ASD bridge-type structures)

For connections in which slip prevention is a strength limit state

$\phi = 0.85$ (LRFD)
$\Omega = 1.76$ (ASD building-type structures)
$\Omega = 1.97$ (ASD bridge-type structures)

where

μ = mean slip coefficient
= 0.50 for aluminum surfaces abrasion blasted with coal slag to SSPC SP-5 to an average substrate profile of 2.0 mils (0.05 mm) in contact with similar aluminum surfaces or zinc painted steel surfaces with a maximum dry film thickness of 4 mils (0.1 mm) (Class B surfaces). Determine slip coefficients for other surfaces in accordance with the RCSC specification Appendix A.
h_{sc} = hole factor determined as follows:
  a) for standard size holes $h_{sc} = 1.00$
  b) for oversized and short-slotted holes $h_{sc} = 0.85$
  c) for long-slotted holes perpendicular to the direction of load $h_{sc} = 0.70$
  d) for long-slotted holes parallel to the direction of load $h_{sc} = 0.60$
T_b = minimum fastener tension specified in the RCSC specification Table 8.1
N_s = number of slip planes

J.3.8.6 Washers

Washers shall be used under bolt heads and under nuts. At a long slotted hole in an outer ply, a galvanized steel plate washer or bar at least 5⁄16 in. (8 mm) thick with standard holes, shall be used. The plate washer or bar shall completely cover the slot but need not be hardened. Where the outer face of the bolted parts has a slope greater than 1:20 with respect to a plane normal to the bolt axis, a beveled washer shall be used.

J.3.9 Lockbolts

Lockbolts shall meet the requirements in this *Specification* for conventional bolts and be installed in conformance with the lockbolt manufacturer's specifications. The bearing areas under the head and collar shall not be less than those of a conventional bolt and nut.

J.3.10 Long Grips

If the grip (total thickness of parts being fastened) of an aluminum bolt exceeds 4.5D, the bolt's nominal shear strength shall be reduced by dividing by $[½ + G_f/(9D)]$ where G_f is the grip and D is the bolt's nominal diameter.

J.4 Rivets

J.4.1 Rivet Material

Rivets shall be aluminum meeting ASTM B 316 or 300 series stainless steel. Carbon steel shall not be used unless the aluminum is joined to carbon steel (see Section M.7.1) and corrosion resistance of the structure is not required or the structure is protected against corrosion.

J.4.2 Holes for Cold-Driven Rivets

The finished diameter of holes for cold-driven rivets shall not be more than 4% greater than the nominal diameter of the rivet.

J.4.3 Minimum Spacing of Rivets

The distance between rivet centers shall not be less than 3 times the nominal diameter of the rivet.

J.4.4 Minimum Edge Distance of Rivets

The distance from the center of a rivet to an edge of a part shall not be less than 1.5 times the nominal diameter of the rivet. See Section J.4.7 for the effect of edge distance on the bearing strength.

J.4.5 Rivet Tension

Aluminum rivets shall not be used to carry tensile loads.

J.4.6 Rivet Shear

For aluminum rivets, the design shear strength ϕR_n and the allowable shear strength R_n/Ω shall be determined for the limit state of shear rupture as follows:

$\phi = 0.65$ (LRFD)
$\Omega = 2.34$ (ASD building-type structures)
$\Omega = 2.64$ (ASD bridge-type structures)

$$R_n = \pi D_h^2 F_{su}/4 \qquad \text{(J.4-1)}$$

where

D_h = nominal diameter of the hole (See Section J.4.2 for hole size limits and Section J.4.9 for hollow-end rivets).
F_{su} = shear ultimate strength of the rivet (See Table A.3.9 or Table A.3.9M).

J.4.7 Rivet Bearing

The design bearing strength ϕR_n and the allowable bearing strength R_n/Ω shall be determined for the limit state of bearing as follows:

$\phi = 0.75$ (LRFD)
$\Omega = 1.95$ (ASD building-type structures)
$\Omega = 2.20$ (ASD bridge-type structures)

$$R_n = d_e t F_{tu} \le 2 D_h t F_{tu} \qquad \text{(J.4-2)}$$

where

d_e = distance from the center of the rivet to the edge of the part in the direction of force.
t = for plain holes, nominal thickness of the connected part; for countersunk holes, nominal thickness of the connected part less ½ the countersink depth
F_{tu} = tensile ultimate strength of the connected part
D_h = nominal diameter of the hole

J.4.8 Blind Rivets

Grip lengths and hole sizes for blind rivets shall comply with the manufacturer's specifications.

J.4.9 Hollow-End (Semi-Tubular) Rivets

The shear strength of hollow-end rivets with solid cross sections for a portion of the length shall be taken equal to the strength of solid rivets of the same material if the bottom of the cavity is at least 25% of the rivet diameter from the plane of shear.

J.5 Tapping Screws

This section applies to tapping screws with a nominal diameter D from 0.164 in. (4.2 mm) (No. 8) through 0.25 in. (6.3 mm). Screws shall be thread-forming or thread-cutting, with or without a self-drilling point.

Screws shall be installed in accordance with the manufacturer's specifications.

J.5.1 Screw Material

Screws shall be:

a) aluminum,
b) 300 series stainless steel, or
c) if the screw will not be exposed to contact with liquid water or humidity near the dew point in its intended service:
    1) 400 series stainless steel with a minimum nominal composition of 16% chromium and a Rockwell hardness less than C35 in the load bearing portion of the shank, or
    2) coated carbon steel with a Rockwell hardness less than C35 in the load-bearing portion of the shank. Screws shall be zinc coated per ASTM A 123, A 641,

or B 695 or nickel/chromium plated per ASTM B 456, Type SC. If other coatings are used, their thickness shall be sufficient to provide corrosion protection for the intended service.

J.5.2 Holes for Screws

The nominal diameter of unthreaded holes for screws shall not exceed the nominal diameter of the screw by more than $\frac{1}{16}$ in. (1.6 mm).

The nominal diameter of threaded holes for screws shall not exceed that given in Tables J.5.1 and J.5.2.

J.5.3 Minimum Spacing of Screws

The distance between screw centers shall not be less than 2.5 times the nominal diameter of the screw.

Table J.5.1
HOLE DIAMETERS FOR TYPE AB, B, AND BP SCREWS

Screw Size	Metal Thickness (in.)	Hole Diameter (in.) (note 1)	Drill Size
8	0.030	0.116	32
	0.036	0.120	31
	0.048	0.128	30
	0.060	0.136	29
	0.075	0.140	28
	0.105	0.147	26
	0.125	0.147	26
	0.135	0.149	25
	0.162 to 0.375	0.152	24
10	0.036	0.144	27
	0.048	0.144	27
	0.060	0.144	27
	0.075	0.147	26
	0.105	0.147	26
	0.125	0.154	23
	0.135	0.154	23
	0.164	0.159	21
	0.200 to 0.375	0.166	19
12	0.048	0.161	20
	0.060	0.166	19
	0.075	0.173	17
	0.105	0.180	15
	0.125	0.182	14
	0.135	0.182	14
	0.164	0.189	12
	0.200 to 0.375	0.196	9
¼	0.060	0.199	8
	0.075	0.201	7
	0.105	0.204	6
	0.125	0.209	4
	0.135	0.209	4
	0.164	0.213	3
	0.187	0.213	3
	0.194	0.221	2
	0.200 to 0.375	0.228	1

Note: for material thicknesses not given, use the next smaller thickness.

J.5.4 Minimum Edge Distance of Screws

The distance from the center of a screw to an edge of a part shall not be less than 1.5 times the nominal diameter of the screw. See Section J.5.6.1 for the effect of edge distance on the bearing strength.

J.5.5 Screwed Connection Tension

Screws in holes or screw slots and subjected to tension shall be designed for the limit states of pull-out, pull-over, and screw tensile rupture. The design tension strength ϕR_n and the allowable tension strength R_n/Ω shall be determined as follows:

$\phi = 0.50$ (LRFD)
$\Omega = 3.0$ (ASD building-type structures)
$\Omega = 3.5$ (ASD bridge-type structures)

The nominal strength R_n for the limit state of pull-out shall be determined in accordance with Section J.5.5.1.
The nominal strength R_n for the limit state of pull-over shall be determined in accordance with Section J.5.5.2.
The nominal strength R_n for the limit state of screw tensile rupture shall be determined in accordance with Section J.5.5.3.

For screws subjected to tension, the head of the screw or washer, if a washer is provided, shall have a nominal diameter not less than $\frac{5}{16}$ in. (8 mm). Washers shall have a nominal thickness not less than 0.050 in. (1.3 mm).

J.5.5.1 Pull-Out

J.5.5.1.1 Screws in Holes

The nominal strength R_n for the limit state of pull-out of a screw in a hole is:

a) For UNC threads (screw types C, D, F, G, and T)
  1) for 0.060 in. $\le L_e \le$ 0.125 in. (1.5 mm $\le L_e \le$ 3 mm)

$$R_n = K_s D L_e F_{ty2} \qquad \text{(J.5-1)}$$

where

K_s = 1.01 for 0.060 in. $\le L_e <$ 0.080 in. (1.5 mm $\le L_e <$ 2 mm)
K_s = 1.20 for 0.080 in. $\le L_e \le$ 0.125 in. (2 mm $\le L_e \le$ 3 mm)
F_{ty2} = tensile yield strength of member not in contact with the screw head
D = nominal diameter of the screw

  2) for 0.125 in. $< L_e <$ 0.25 in. (3 mm $< L_e <$ 6.3 mm)

$$R_n = 1.2DF_{ty2}(0.25 - L_e) + 1.16A_{sn}F_{tu2}(L_e - 0.125) \qquad \text{(J.5-2)}$$

Table J.5.2
HOLE DIAMETERS FOR TYPE C, D, F, AND T SCREWS

	Metal Thickness (in.)										
screw size	**0.050**	**0.060**	**0.083**	**0.109**	**0.125**	**0.140**	**3/16**	**¼**	**5/16**	**3/8**	**½**
	Hole Diameter (in.)										
8–32	0.1360	0.1360	0.1360	0.1405	0.1405	0.1440	0.1470	0.1495	0.1495		
10–24	0.1495	0.1520	0.1540	0.1570	0.1590	0.1610	0.1660	0.1719	0.1730	0.1730	
10–32	0.1610	0.1610	0.1610	0.1660	0.1660	0.1660	0.1719	0.1770	0.1770	0.1770	
12–24		0.1770	0.1800	0.1820	0.1850	0.1875	0.1910	0.1990	0.1990	0.1990	0.1990
¼–20			0.2055	0.2090	0.2130	0.2130	0.2210	0.2280	0.2280	0.2280	0.2280
¼–28			0.2188	0.2210	0.2210	0.2210	0.2280	0.2344	0.2344	0.2344	0.2344

Note: for material thicknesses not given, use the next smaller thickness.

where

A_{sn} = thread stripping area of internal thread per unit length of engagement

F_{tu2} = tensile ultimate strength of member not in contact with the screw head

3) for 0.25 in. $\le L_e \le$ 0.375 in. (6.3 mm $\le L_e \le$ 10 mm)

$$R_n = 0.58 A_{sn} L_e F_{tu2} \qquad \text{(J.5-3)}$$

b) For spaced threads (screw types AB, B, BP, BF, and BT)

1) for 0.038 in. $\le L_e \le 2/n$ (1 mm $< L_e < 2/n$)

$$R_n = K_s D L_e F_{ty2} \qquad \text{(J.5-4)}$$

where

K_s = 1.01 for 0.038 in. $\le L_e <$ 0.080 in. (1 mm $\le L_e <$ 2 mm)

K_s = 1.20 for 0.080 in. $\le L_e < 2/n$ (2 mm $\le L_e < 2/n$)

2) for $2/n < L_e < 4/n$

$$R_n = 1.2 D F_{ty2} (4/n - L_e) + 3.26 D F_{tu2} (L_e - 2/n) \qquad \text{(J.5-5)}$$

3) for $4/n \le L_e \le$ 0.375 in. ($4/n \le L_e \le$ 8 mm)

$$R_n = 1.63 D L_e F_{tu2} \qquad \text{(J.5-6)}$$

J.5.5.1.2 Screws in Screw Slots

The nominal strength R_n for the limit state of pull-out of a screw in a screw slot with the dimensions shown in Figure J.5.1 and Table J.5.3 is:

$$R_n = 0.29 D L_e F_{tu} \qquad \text{(J.5-7)}$$

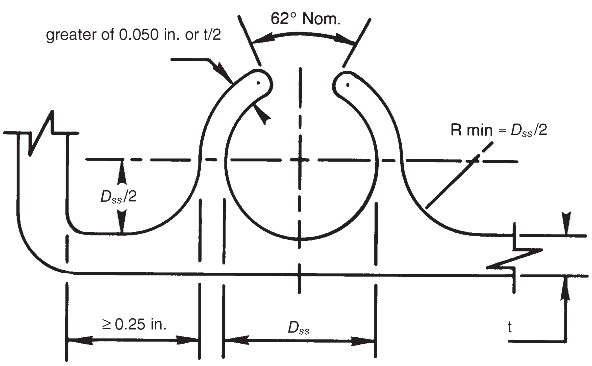
where

D = nominal diameter of the screw

F_{tu} = tensile ultimate strength of the extrusion

The screw embedment length in the screw slot L_e shall not be less than $2D$.

Typical location away from corner



Typical corner location

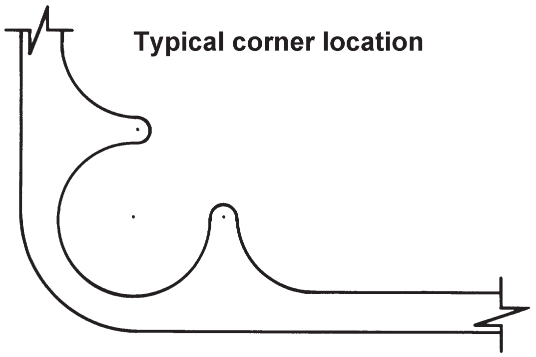


Figure J.5.1

Table J.5.3
SCREW SLOT DIMENSIONS

Screw Size	Screw Diameter D (in.)	D_{ss} (in.) +/– 0.007 in.
8	0.164	0.147
10	0.190	0.169
12	0.216	0.190
¼	0.250	0.228

J.5.5.2 Pull-Over

a) The nominal strength R_n for the limit state of pull-over for non-countersunk screws is:

$$R_n = C_{pov} t_1 F_{tu1}(D_{ws} - D_h) \tag{J.5-8}$$

where

C_{pov} = 1.0 for valley fastening and 0.7 for crown fastening
t_1 = nominal thickness of the part in contact with the screw head or washer
F_{tu1} = tensile ultimate strength of the part in contact with the screw head or washer
D_{ws} = larger of the nominal washer diameter and the screw head diameter, but no greater than ⅝ in. (16 mm). (See Section J.5.5 for the washer thickness requirement.)
D_h = nominal diameter of the hole in the material under the screw head

The nominal pull-over strength for non-countersunk screws need not be less than the nominal pull-over strength computed from Equation J.5-10 for countersunk screws.

Alternately, for parts with: 1) a nominal thickness of at least 0.040 in., 2) holes with the nominal diameters given in Table J.5.4, and 3) $t_1/D_{ws} \le 0.5$, the nominal strength R_n for the limit state of pull-over for non-countersunk screws with all-metal washers is:

$$R_n = (1.0 + 1.7t_1/D_{ws})D_{ws}\, t_1\, F_{ty1} \tag{J.5-9}$$

where

t_1 = nominal thickness of the part in contact with the screw head
F_{ty1} = tensile yield strength of the part in contact with the screw head
D_{ws} = nominal diameter of the washer. The washer may be integral with the screw head.

Table J.5.4
HOLE SIZES FOR EQUATION J.5-9

Screw Size	Screw Diameter (in.)	Hole Diameter (in.)	Drill Size
8	0.164	0.177	16
10	0.190	0.201	7
12	0.216	0.228	1
¼	0.250	0.266	H

b) The nominal strength R_n for the limit state of pull-over for countersunk screws with an 82° nominal angle head is:

$$R_n = (0.27 + 1.45t_1/D)Dt_1F_{ty1} \tag{J.5-10}$$

for 0.06 in. $\le t_1 < 0.19$ in. (1.5 mm $\le t_1 < 5$ mm) and $t_1/D \le 1.1$. If $t_1/D > 1.1$, use $t_1/D = 1.1$

where

F_{ty1} = tensile yield strength of the part in contact with the screw head

J.5.5.3 Screw Tension

For aluminum screws, the nominal strength R_n of a screw for the limit state of tensile rupture is:

$$R_n = A_r F_{tu}/1.25 \tag{J.5-11}$$

where

A_r = root area of the screw
F_{tu} = tensile ultimate strength of the screw
= 68 ksi for 7075-T73 screws,
= 62 ksi for 2024-T4 screws

J.5.6 Screwed Connection Shear

Screws in holes and subjected to shear shall be designed for the limit states of bearing, tilting, and screw shear rupture. The design shear strength ϕR_n and the allowable shear strength R_n/Ω shall be determined as follows:

$\phi = 0.50$ (LRFD)
$\Omega = 3.0$ (ASD building-type structures)
$\Omega = 3.5$ (ASD bridge-type structures)

The nominal strength R_n for the limit state of bearing shall be determined in accordance with Section J.5.6.1.

The nominal strength R_n for the limit state of tilting shall be determined in accordance with Section J.5.6.2.

The nominal strength R_n for the limit state of screw shear rupture shall be determined in accordance with Section J.5.6.3.

J.5.6.1 Screw Bearing

The nominal strength R_n for the limit state of bearing is

$$R_n = d_e t F_{tu} \le 2DtF_{tu} \tag{J.5-12}$$

where

d_e = distance from the center of the screw to the edge of the part in the direction of force.
t = for plain holes, nominal thickness of the connected part; for countersunk holes, nominal thickness of the connected part less ½ the countersink depth.
F_{tu} = tensile ultimate strength of the connected part
D = nominal diameter of the screw

J.5.6.2 Screw Tilting

For $t_2 \leq t_1$, the nominal strength R_n for the limit state of tilting is:

$$R_n = 4.2(t_2^3 D)^{1/2} F_{tu2} \qquad \text{(J.5-13)}$$

For $t_2 > t_1$, tilting is not a limit state.

J.5.6.3 Screw Shear

For aluminum screws, the nominal strength R_n for the limit state of screw shear rupture is:

$$R_n = A_r F_{su}/1.25 \qquad \text{(J.5-14)}$$

where

A_r = root area of the screw
F_{su} = shear ultimate strength of the screw
= 41 ksi for 7075-T73 screws,
= 37 ksi for 2024-T4 screws

J.6 Affected Elements of Members and Connectors

This section applies to elements of members at connections and connectors such as plates, gussets, angles, and brackets.

J.6.1 Strength of Connectors in Tension

The design strength ϕR_n and the allowable strength R_n/Ω of connectors in tension shall be determined in accordance with Chapter D.

J.6.2 Strength of Connectors in Shear

The design strength ϕR_n and the allowable strength R_n/Ω of connectors in shear shall be the lesser value for the limit states of shear yielding and shear rupture.

a) For shear yielding of connectors:
$R_n = F_{sy} A_g$
$\phi = 1.00$ (LRFD)
$\Omega = 1.50$ (ASD building-type structures)
$\Omega = 1.68$ (ASD bridge-type structures)
b) For shear rupture of connectors:
$R_n = F_{su} A_{nv}$
$\phi = 0.75$ (LRFD)
$\Omega = 1.95$ (ASD building-type structures)
$\Omega = 2.20$ (ASD bridge-type structures)

J.6.3 Block Shear Strength

The design strength ϕR_n and the allowable strength R_n/Ω shall be determined for the limit state of block shear rupture as follows:

$\phi = 0.75$ (LRFD)
$\Omega = 1.95$ (ASD building-type structures)
$\Omega = 2.20$ (ASD bridge-type structures)

a) For bolted connections on a failure path with shear on some segments and tension on the other segments:

For $F_{tu}A_{nt} \geq F_{su}A_{nv}$

$$R_n = F_{sy}A_{gv} + F_{tu}A_{nt} \qquad \text{(J.6-1)}$$

otherwise

$$R_n = F_{su}A_{nv} + F_{ty}A_{gt} \qquad \text{(J.6-2)}$$

b) For welded connections on a failure path with shear on some segments and tension on the other segments:

For $F_{tu}A_{gt} \geq F_{su}A_{gv}$

$$R_n = F_{sy}A_{gv} + F_{tu}A_{gt} \qquad \text{(J.6-3)}$$

otherwise

$$R_n = F_{su}A_{gv} + F_{ty}A_{gt} \qquad \text{(J.6-4)}$$

where

A_{gv} = gross area in shear
A_{gt} = gross area in tension
A_{nv} = net area in shear
A_{nt} = net area in tension

J.6.4 Strength of Connectors in Compression

The design strength ϕR_n and the allowable strength R_n/Ω of connectors in compression shall be determined in accordance with Chapter E.

J.7 Bearing Strength of Flat Surfaces and Pins

The design bearing strength ϕR_n and the allowable bearing strength R_n/Ω of surfaces in contact shall be determined as follows:

$\phi = 0.75$ (LRFD)
$\Omega = 1.95$ (ASD building-type structures)
$\Omega = 2.20$ (ASD bridge-type structures)

a) For pins in holes

$$R_n = d_e t F_{tu}/1.5 \leq 1.33 D t F_{tu} \qquad \text{(J.7-1)}$$

where

D = nominal diameter of the pin
t = thickness of the connected part
d_e = distance from the center of a pin to the edge of a part, which shall not be less than $1.5D$

b) For flat surfaces

$$R_n = 1.33F_{tu}A_{pb} \tag{J.7-2}$$

where A_{pb} = projected bearing area

J.8 Flanges and Webs with Concentrated Forces

J.8.1 Crippling of Flat Webs

The design strength ϕR_n and the allowable strength R_n/Ω for the limit state of web crippling shall be determined as follows:

$\phi = 0.75$ (LRFD)
$\Omega = 1.95$ (ASD building-type structures)
$\Omega = 2.20$ (ASD bridge-type structures)

For concentrated forces applied at a distance from the member end that equals or exceeds $d/2$:

$$R_n = \frac{C_{wa}(N + C_{w1})}{C_{wb}} \tag{J.8-1}$$

For concentrated forces applied at a distance from the member end that is less than $d/2$:

$$R_n = \frac{1.2C_{wa}(N + C_{w2})}{C_{wb}} \tag{J.8-2}$$

where:

$$C_{wa} = t^2 \sin\theta\ (0.46F_{cy} + 0.02\sqrt{EF_{cy}}) \tag{J.8-3}$$

$$C_{wb} = C_{w3} + R_i\ (1 - \cos\theta) \tag{J.8-4}$$

C_{w1} = 5.4 in. (140 mm)
C_{w2} = 1.3 in. (33 mm)
C_{w3} = 0.4 in. (10 mm)
d = member depth
N = length of the bearing at the concentrated force
R_i: for shapes made by bending, R_i = inside bend radius at the juncture of the flange and web; for extruded shapes, $R_i = 0$
t = web thickness
θ = angle between the plane of web and the plane of the bearing surface ($\theta \le 90°$)

J.8.2 Bearing Stiffeners

Bearing stiffeners at concentrated forces shall be sufficiently connected to the web to transmit the concentrated force. Such stiffeners shall form a tight and uniform bearing against the flanges unless welds designed to transmit the full concentrated force are provided between flange and stiffener. Only the part of a stiffener cross section outside the flange-to-web fillet shall be considered effective in bearing.

The bearing stiffener shall meet the requirements of Chapter E with the length of the stiffener equal to the height of the web.

J.8.3 Combined Crippling and Bending of Flat Webs

Combinations of bending and concentrated forces applied at a distance of one-half or more of the member depth from the member end shall be limited by the following formula:

$$\left(\frac{P}{P_c}\right)^{1.5} + \left(\frac{M}{M_c}\right)^{1.5} \le 1.0 \tag{J.8-5}$$

where

P = concentrated force
M = bending moment in the member at the location of the concentrated force
For LRFD
P_c = design concentrated force determined in accordance with Section J.8.1
M_c = design flexural strength determined in accordance with Chapter F
For ASD
P_c = allowable concentrated force determined in accordance with Section J.8.1
M_c = allowable flexural strength determined in accordance with Chapter F

J.9 Roofing and Siding Connections

J.9.1 Endlaps

Minimum endlaps shall be those given in Table J.9.1.

Table J.9.1
MINIMUM ENDLAPS

Depth of section d	Roofing slope > 2 on 12, < 3 on 12	Roofing slope ≥ 3 on 12	Siding
$d \le 1$ in. (25 mm)	—	6 in. (150 mm)	4 in. (100 mm)
1 in. (25 mm) $< d <$ 2 in. (50 mm)	9 in. (230 mm)	6 in. (150 mm)	4 in. (100 mm)
$d \ge 2$ in. (50 mm)	9 in. (230 mm)	6 in. (150 mm)	6 in. (150 mm)

J.9.2 Sidelaps

For sinusoidal corrugated sheet, the minimum sidelap width for roofing shall equal the pitch of the corrugations, and the minimum sidelap width for siding shall equal half the pitch.

For trapezoidal sheet with a depth greater than 1 in. (25 mm) the minimum sidelap for both roofing and siding shall have a developed width equal to the width of the narrowest flat plus 2 in. (50 mm). Trapezoidal sheet with a depth of 1 in. (25 mm) or less shall have a sidelap of proven design with an anti-siphoning feature.

J.9.3 Fasteners in Laps

The minimum size of fasteners used in end laps and side laps shall be #12 (5.5 mm) for screws and 3⁄16 in. (5 mm) diameter for rivets. The maximum spacing for sidelap fasteners shall be 12 in. (300 mm). Endlap fasteners shall be no more than 2 in. (50 mm) from the end of the overlapping sheet.

Chapter L Design for Serviceability

L.1 General Provisions

Serviceability is the preservation of a structure's function under service load combinations.

L.2 Camber

If camber is required, its magnitude, direction, and location shall be shown on the structural drawings.

L.3 Deflections

Deflections caused by service load combinations shall not impair serviceability.

For shapes with elements addressed by Sections B.5.4.1, B.5.4.2, B.5.4.3, B.5.5.1, or B.5.5.3 with $f_a > F_e$, effective widths shall be used to determine the moment of inertia used to calculate deflections.

The effective width b_e of such elements in compression is:

$$\text{If } f_a \le F_e,\ b_e = b \qquad \text{(L.3-1)}$$

$$\text{If } f_a > F_e,\ b_e = b\sqrt{F_e/f_a} \qquad \text{(L.3-2)}$$

where

b_e = element's effective width

b = element's width

F_e = element's elastic local buckling stress determined using Section B.5.6

f_a = maximum compressive stress in the element from service load combinations

The effective width of elements subjected to flexure shall be placed next to the compression flange. Bending deflections shall be calculated using the compressive modulus of elasticity given in Table A.3.4 or Table A.3.4M.

L.4 Vibration

Vibration caused by service load combinations shall not impair serviceability.

L.5 Wind-Induced Motion

Wind-induced motion caused by service load combinations shall not impair serviceability.

L.6 Expansion and Contraction

Thermal expansion and contraction shall not impair serviceability.

L.7 Connection Slip

Connection slip under service load combinations shall be precluded if it would impair serviceability.

Chapter M Fabrication and Erection

M.1 Layout

M.1.1 Punch and Scribe Marks

Punched or scribed layout marks shall not remain on fabricated material designed for fatigue.

M.1.2 Temperature Correction

A temperature correction shall be applied where necessary in the layout of dimensions. The coefficient of thermal expansion used shall be per Section A.3.1.

M.2 Cutting

M.2.1 Methods

Cutting shall be by shearing, sawing, nibbling, routing, arc cutting, laser, or abrasive water jet. Edges which have been arc or laser cut shall be planed to remove edge cracks. Oxygen cutting is prohibited.

M.2.2 Edge Quality

Cut edges shall be true, smooth, and free from excessive burrs or ragged breaks.

M.2.3 Re-entrant Corners

Re-entrant corners shall be filleted.

M.3 Heating

Alloys 535.0, 5083, 5086, 5154, and 5456 shall not be held at temperatures from 150°F (66°C) to 450°F (230°C). To hot form such alloys, they shall be 1) rapidly heated to a temperature not to exceed 550°F (290°C), 2) formed before the metal cools below 450°F (230°C), 3) rapidly cooled from 450°F to 150°F, and 4) designed using O temper strength.

For other alloys heated above 200°F (93°C) during fabrication other than welding, time at temperature shall be limited as specified in Section A.3.1.1.

M.4 Holes

M.4.1 Fabrication Methods

Holes shall be punched or drilled. Holes shall be free from excessive burrs or ragged edges. Punching shall not be used for castings or if the metal thickness is greater than the diameter of the hole. The amount by which the diameter of a sub-punched hole is less than that of the finished hole shall be at least ¼ the thickness of the piece but not less than $\frac{1}{32}$ in. (0.8 mm).

M.4.2 Hole Alignment

If holes must be enlarged to admit fasteners, they shall be reamed. Poor matching holes shall be rejected. Holes shall not be drifted in a manner that distorts the metal. All chips and foreign matter between contacting surfaces shall be removed before assembly.

M.5 Bending

Bend radii shall be large enough to avoid cracking.

M.6 Finishes

M.6.1 Where Protective Coating Is Required

Aluminum shall be provided with a protective coating when:

a) alloy 2014 is in the presence of moisture,
b) aluminum would otherwise be in contact with or fastened to dissimilar materials as described in Section M.7,
c) aluminum is exposed to corrosive conditions.

M.6.2 Surface Preparation

Surfaces to be painted shall be prepared immediately before painting by: a) chemical cleaning (such as a solution of phosphoric acid and organic solvents), or b) abrasion blasting, or c) unsealed anodizing, or d) chemical conversion coating, or e) using a procedure specified by the coating supplier.

M.6.3 Abrasion Blasting

Abrasion blasting shall not be used if it distorts, perforates, or significantly reduces the thickness of the material blasted.

M.7 Contact with Dissimilar Materials

Where aluminum is in contact with or fastened to the materials specified in Sections M.7.1 through M.7.3, direct contact between the aluminum and the other material shall be prevented as specified in those sections or by placing a compatible, nonporous isolator between the aluminum and the other material.

M.7.1 Steel

Steel surfaces to be placed in contact with uncoated aluminum shall be painted with a coating suitable for the service. Where very corrosive conditions are expected, additional protection can be obtained by applying a sealant that excludes moisture from the joint during service. Aluminized or galvanized steel in contact with aluminum need not be painted. Stainless steel (300 series) in contact with aluminum need not be painted except in high chloride environments.

M.7.2 Wood, Fiberboard, or Other Porous Materials

Aluminum surfaces to be placed in contact with wood, fiberboard, or other porous material that absorbs water shall be factory painted or given a heavy coat of alkali-resistant bituminous paint or other coating providing the equivalent protection before installation.

M.7.3 Concrete or Masonry

Aluminum shall not be embedded in concrete with corrosive additives such as chlorides if the aluminum is electrically connected to steel.

Unless the concrete or masonry remains dry after curing and no corrosive additives such as chlorides are used, aluminum surfaces to be placed next to or embedded in concrete or masonry shall be:

a) given one coat of suitable paint, such as zinc molybdate primer conforming to Federal Specification TT-P-645B or equivalent, or
b) given a heavy coating of alkali-resistant bituminous paint, or
c) isolated with a suitable plastic tape or other isolation material.

M.7.4 Runoff from Heavy Metals

Aluminum shall not be exposed to water that has come in contact with a heavy metal such as copper. The heavy metal shall be painted or coated, the drainage from the metal diverted away from the aluminum, or painted aluminum shall be used.

M.8 Fabrication Tolerances

A fabricated member shall not vary from straight or from its intended curvature by more than its length divided by 960.

M.9 Welding

Welding shall comply with the AWS D1.2 *Structural Welding Code—Aluminum.* Filler alloys shall be selected from Tables M.9.1 and M.9.2.

The contract documents shall specify if visual inspection is required to be performed by AWS certified welding inspectors. When inspection other than visual inspection is required, the contract documents shall state the method, extent, inspector qualifications, and acceptance criteria for such inspection.

M.10 Bolt Installation

Unless the joint is a slip-critical connection, bolts need only be installed snug tight, the tightness that exists when all plies in a joint are in firm but not necessarily continuous contact. Slip-critical connections shall be tightened and inspected in accordance with the RCSC *Specification for Structural Joints Using ASTM A325 or A490 Bolts.*

M.11 Riveting

M.11.1 Driven Head

The driven head of aluminum rivets shall be flat or cone-point, with dimensions as follows:

a) Flat heads shall have a diameter at least 1.4 times the nominal diameter of the rivet and a height at least 0.4 times the nominal diameter of the rivet.
b) Cone-point heads shall have a diameter at least 1.4 times the nominal diameter of the rivet and a height to the apex of the cone at least 0.65 times the nominal diameter of the rivet. The nominal included angle at the apex of the cone shall be 127°.

M.11.2 Hole Filling

Rivets shall fill holes completely. Rivet heads shall be concentric with the rivet holes and shall be in continuous contact with the surface of the part joined.

M.11.3 Defective Rivets

Defective rivets shall be removed by drilling. The drill bit diameter shall not exceed the diameter of the replacement rivet.

M.12 Erection Tolerances

Tolerances on erected dimensions shall be suitable for the intended service and consistent with the geometric imperfections used in the stability analysis conducted in accordance with Chapter C.

Table M.9.1
WELD FILLERS FOR WROUGHT ALLOYS

Base Metal / Base Metal	1060, 1100, 3003, Alclad 3003	2219	3004 Alclad 3004	5005, 5050	5052	5083, 5456	5086	5154	5454	6005, 6005A, 6061, 6063, 6082, 6105, 6351, 6463	7005
7005	5356 (5183, 5556)	DNW	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5556 (5183)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5556 (5183, 5356)
6005, 6005A, 6061, 6063, 6082, 6105, 6351, 6463	4043 (4047)	4145	5356 (4043, 4047, 5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (4043, 4047, 5183, 5556)	
5454	5356 (5183, 5556)	DNW	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5654 (5183, 5356, 5556)	5554 (5183, 5356, 5556)		
5154	5356 (5183, 5556)	DNW	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5654 (5183, 5356, 5556)			
5086	5356 (5183, 5556)	DNW	5356 (5183,5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)				
5083, 5456	5356 (5183, 5556)	DNW	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)	5556 (5183)					
5052	5356 (5183, 5556)	DNW	5356 (5183, 5556)	5356 (5183, 5556)	5356 (5183, 5556)						
5005, 5050	4043 (1100, 4047)	DNW	5356 (4043, 4047, 5183, 5556)	5356 (4043, 4047, 5183, 5556)							
3004, Alclad 3004	4043 (4047, 5183, 5356, 5556)	DNW	5356 (5183, 5556)								
2219	4145	2319 (4145)									
1060, 1100, 3003, Alclad 3003	4043 (1100, 4047)										

Notes:
1. This table is for structural applications subjected to normal atmospheric conditions using GTAW or GMAW.
2. DNW = Do Not Weld
3. Fillers in parentheses are acceptable alternates.

Table M.9.2
WELD FILLERS FOR CAST ALLOYS

Base Metal	Base Metal 535.0	 356.0, A356.0, A357.0, 359.0	 354.0, C355.0
1060, 1100, 3003, Alclad 3003	5356	4043 (4047)	4145
2219	DNW	4145	4145
3004, Alclad 3004	5356	4043 (4047)	4145 (4043, 4047)
5005, 5050	5356	4043 (4047)	4145 (4043, 4047)
5052	5356	4043 (4047)	4043 (4047)
5083, 5456	5356	5356	DNW
5086	5356	5356	DNW
5154	5356	4043	DNW
5454	5356	4043 (4047)	4043
6005, 6005A, 6061, 6063, 6082, 6105, 6351, 6463	5356	4043 (4047, 4145, 4643)	4145 (4043, 4047)
7005	5356	4043 (4047)	4145 (4043, 4047)
354.0, C355.0	DNW	4145	4145 (note 1)
356.0, A356.0, A357.0, 359.0	5356	4043 (note 1)	
535.0	5356		

Notes:
1. To weld C355.0 to itself, 4009 may be used; to weld A356.0 to itself, 4010 may be used; to weld A357.0 to itself, 4011 may be used.
2. DNW = Do Not Weld
3. Fillers in parentheses are acceptable alternates.

Appendix 1 Testing

1.1 General Provisions

Testing is an acceptable method for determining the nominal strengths of aluminum members, assemblies, or connections whose nominal strengths cannot be determined in accordance with Chapters A through L. Tests shall be conducted by a testing laboratory accredited by a nationally recognized accreditation service.

General provisions for testing are given in Sections 1.2 and 1.3. Specific provisions for roofing and siding are given in Section 1.4.

1.2 Test Loading and Deflections

Test loading and supports shall be representative of conditions during service.

In tests that require measurement of deflection, a preload that is 20% of the design load shall be applied to set the specimen before testing. During testing, deflections shall be measured at the supports as well as at the point of maximum deflection, and the difference shall be taken as the specimen deflection.

As an alternative, the structural performance of exterior aluminum fenestration products such as windows, curtain walls, and doors shall be determined in accordance with ASTM E 330.

1.3 Number of Tests and the Evaluation of Test Results

1.3.1 Tests for Determining Mechanical Properties

In determining yield strength and ultimate strength of material or fasteners, sufficient tests shall be conducted to statistically establish the strength which 99% of the material is expected to exceed with a confidence of 95%. This strength shall be calculated as follows:

$$X_a = X_m - KS_x \tag{1.3-1}$$

where

X_a = strength which 99% of the material is expected to exceed with a confidence of 95%

X_m = mean of the test results

S_x = standard deviation of the test results

K = statistical coefficient based on the number of tests n. K is a one-sided factor for 99% of the population exceeding X_a with a confidence of 95%. Values of K for the following values of n are:

n	*K*	*n*	*K*
3	10.55	18	3.370
4	7.042	19	3.331
5	5.741	20	3.295
6	5.062	21	3.262
7	4.641	22	3.233
8	4.353	23	3.206
9	4.143	24	3.181
10	3.981	25	3.158
11	3.852	30	3.064
12	3.747	35	2.994
13	3.659	40	2.941
14	3.585	45	2.897
15	3.520	50	2.863
16	3.463	100	2.684
17	3.415		

1.3.2 Tests for Determining Structural Performance

For members and assemblies, no fewer than four identical specimens shall be tested. If any individual result deviates from the average result by more than 10%, at least three more tests shall be performed.

For LRFD, the design strength shall be the average of all test results multiplied by the resistance factor ϕ determined as follows:

$$\phi = 1.5 M_m F_m e^{-\beta_o \sqrt{V_M^2 + V_F^2 + C_n V_P^2 + V_Q^2}} \tag{1.3-2}$$

For ASD, the allowable strength shall be the average of all test results divided by the safety factor Ω determined as follows:

$$\Omega = \frac{1.05\alpha + 1}{M_m F_m (\alpha + 1)} e^{\beta_o \sqrt{V_M^2 + V_F^2 + C_n V_P^2 + V_Q^2}} \tag{1.3-3}$$

where

$\alpha = D_n/L_n$; in lieu of calculation by the above formula, $\alpha = 0.2$

β_o = the target reliability index
= 2.5 for columns, beams and beam-columns,
= 3.0 for tension members, and
= 3.5 for connections.

C_n = correction factor $= \dfrac{n^2 - 1}{n^2 - 3n}$

D_n = nominal dead load

e = base for natural logarithms ≈ 2.72

F_m = mean value of the fabrication factor

L_n = nominal live load

M_m = mean value of the material factor

n = number of tests
X_i = failure load of ith test
X_m = average value of failure loads in all tests

$$= \frac{\sum_{i=1}^{n} X_i}{n}$$

V_F = coefficient of variation of the fabrication factor
V_M = coefficient of variation of the material factor
V_P = coefficient of variation of the ratio of the observed failure loads divided by the average value of all the observed failure loads

$$= \sqrt{\frac{\sum_{i=1}^{n}\left(\frac{X_i}{X_m}\right)^2 - \frac{\left(\sum_{i=1}^{n}\frac{X_i}{X_m}\right)^2}{n}}{n-1}}$$

V_Q = coefficient of variation of the loads
$= \frac{\sqrt{(0.105D_n)^2 + (0.25L_n)^2}}{1.05D_n + L_n}$; in lieu of calculation by the above formula, $V_Q = 0.21$

The following values shall be used when documented statistical data established from a sufficient number of results on material properties does not exist for the member or connection:

M_m = 1.10 for behavior governed by the yield stress
= 1.00 for behavior governed by the ultimate stress
F_m = 1.00
V_M = 0.06
V_F = 0.05 for structural members and bolted connections
= 0.15 for welded connections

In evaluating test results, adjustment shall be made for any differences between the yield strength of the material from which the tested sections are formed and the yield strength specified for the material which the manufacturer intends to use. If the tensile yield strength of the aluminum from which the tested sections are formed is greater than the specified value, the test results shall be adjusted down to the specified yield strength of the aluminum which the manufacturer intends to use. The test results shall not be adjusted upward if the yield strength of the test specimen is less than the specified yield strength. Similar adjustments shall be made on the basis of tensile ultimate strength instead of yield strength when behavior is governed by the tensile ultimate strength.

Adjustments shall also be made for differences between nominal section properties and those of tested sections.

1.4 Testing Roofing and Siding

The bending strength of roofing and siding shall be established from tests when any of the following conditions apply.

a) Web angles are asymmetrical about the centerline of a valley, rib, flute, crimp, or other corrugation;
b) Web angles are less than 45°;
c) Aluminum panels are alternated with panels composed of any material having significantly different strengths or deflection characteristics;
d) Flats spanning from rib to rib or other corrugation in the transverse direction have a width to thickness ratio greater than either of the following:
   (1) $\frac{1230}{\sqrt[3]{q}}$ where q is the design load in psf
   $\left(\frac{447}{\sqrt[3]{q}}\right.$ where q is the design load in kN/m$^2\left.\right)$
   (2) $435\sqrt{\frac{F_{ty}}{q}}$ where F_{ty} is in ksi and q is in psf
   $\left(37\sqrt{\frac{F_{ty}}{q}}\right.$ where F_{ty} is in MPa and q is in kN/m$^2\left.\right)$;
e) Panel ribs, valleys, crimps, or other corrugations are of unequal depths;
f) Specifications prescribe less than one fastener per rib to resist negative or uplift loading at each purlin, girt, or other transverse supporting member; or
g) Panels are attached to supporting members by profile interlocking straps or clips.

1.4.1 Test Method

Tests shall be conducted in accordance with ASTM E 1592.

1.4.2 Different Thicknesses

Only the thinnest and thickest specimens manufactured are required to be tested when panels are of like configuration, differing only in material thickness. Where the failure of the test specimens is from bending stress, the bending strength for intermediate thicknesses shall be interpolated as follows:

$$\log M_i = \log M_1 + \left(\frac{\log t_i - \log t_{\min}}{\log t_{\max} - \log t_{\min}}\right)(\log M_2 - \log M_1) \tag{1.4-1}$$

where

M_i = bending strength of member of intermediate thickness t_i
M_1 = bending strength of member of thinnest material
M_2 = bending strength of member of thickest material
t_i = thickness of intermediate thickness material
$t_{\min}$ = thickness of thinnest material tested
$t_{\max}$ = thickness of thickest material tested

1.4.3 Design and Allowable Strengths

Design strengths shall be determined using the resistance factors given in Chapter F for bending and Chapter J applied to the minimum test strength achieved for fasteners.

Allowable strengths shall be determined using the safety factors given in Chapter F for bending and Chapter J applied to the minimum test strength achieved for fasteners.

1.4.4 Deflections

Live load deflections shall meet the requirements of Section L.3.

Appendix 3 Design for Fatigue

3.1 General Provisions

Welded details, mechanically fastened joints, and wrought material subjected to fatigue shall meet all the static requirements of this *Specification* as well as the requirements of this Appendix. Fatigue design of castings shall be made by testing in accordance with Appendix 1.

Categories of details for fatigue design parameters shall be chosen from Figure 3.1 and Table 3.1.

The maximum and minimum stresses used to calculate the stress range are nominal stresses perpendicular to the expected plane of cracking determined by elastic methods.

3.2 Constant Amplitude Loading

For constant amplitude loading

$$S_{ra} \le S_{rd} \tag{3.2-1}$$

where

S_{ra} = applied stress range, the algebraic difference between the minimum and maximum calculated stress

S_{rd} = allowable stress range

$$S_{rd} = C_f N^{-1/m} \tag{3.2-2}$$

C_f, m = constants from Table 3.2

N = number of cycles to failure

If the applied stress range S_{ra} is less than the constant amplitude fatigue limit given in Table 3.2, no further fatigue consideration shall be needed. The allowable stress range S_{rd} shall not be less than the value from Equation 3.2-2 when $N = 5 \times 10^6$ cycles and shall not be greater than the value from Equation 3.2-2 when $N = 10^5$ cycles.

3.3 Variable Amplitude Loading

For variable amplitude loading:

$$S_{re} \le S_{rd} \tag{3.3-1}$$

where

S_{re} = equivalent stress range

$$S_{re} = \left(\sum_{i=1}^{N_S} \alpha_i S_{ri}^{m}\right)^{1/m} \tag{3.3-2}$$

S_{rd} = allowable stress range

$$S_{rd} = C_f N^{-1/m} \tag{3.3-3}$$

α_i = number of cycles in the spectrum of the *i*th stress range divided by the total number of cycles

S_{ri} = *i*th stress range in the spectrum

C_f, m = constants from Table 3.2

N_S = number of stress ranges in the spectrum

N = number of cycles to failure

The allowable stress range S_{rd} shall not exceed the value from Equation 3.3-3 when $N = 10^5$ cycles.

If the maximum stress range in the spectrum is less than the constant amplitude fatigue limit, no further fatigue assessment is needed.

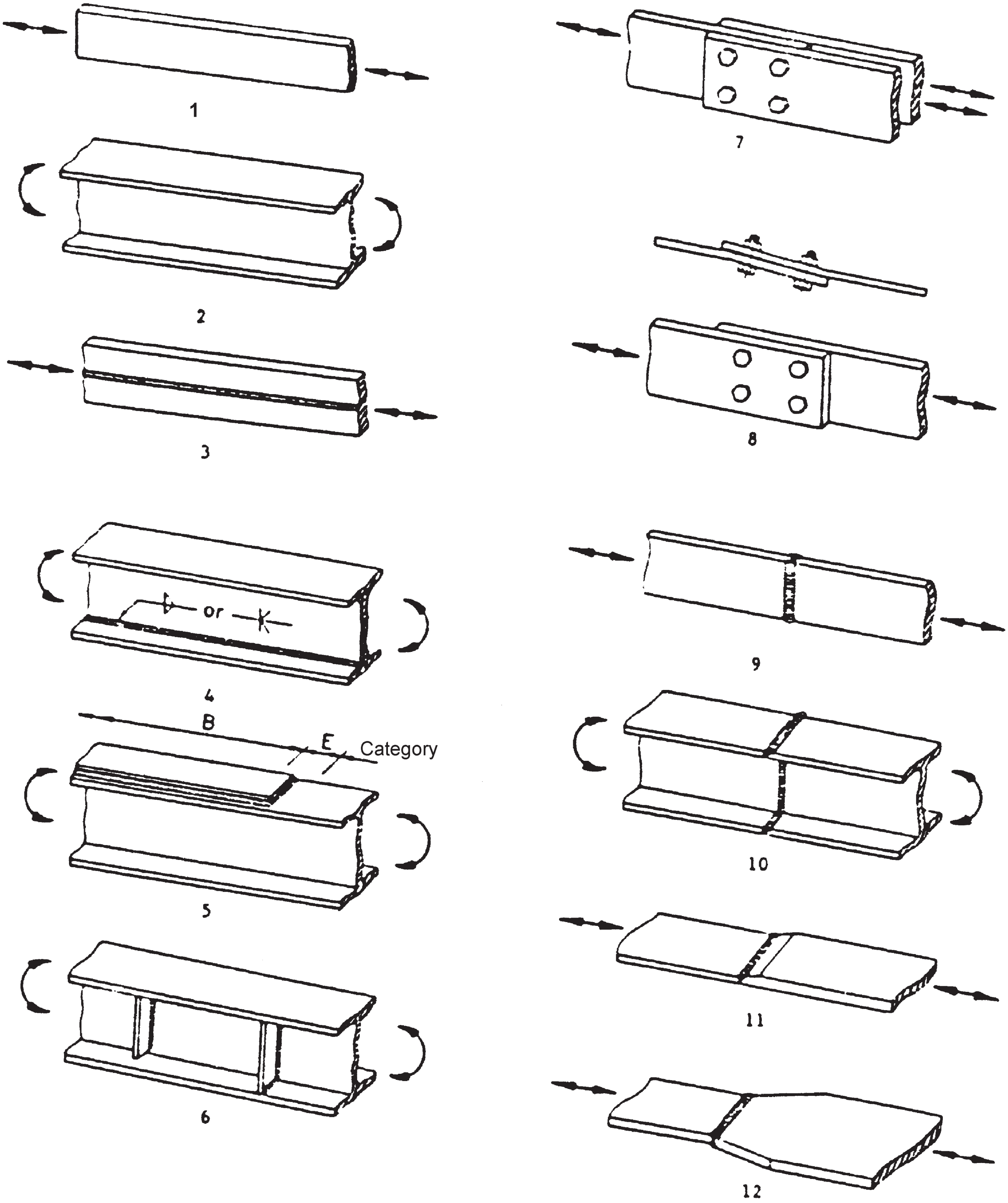
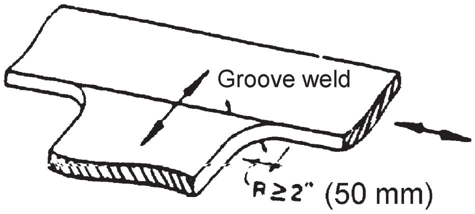


Figure 3.1
FATIGUE DESIGN DETAILS



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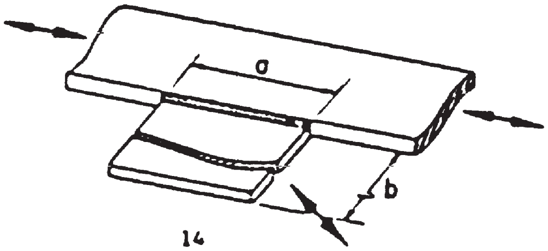

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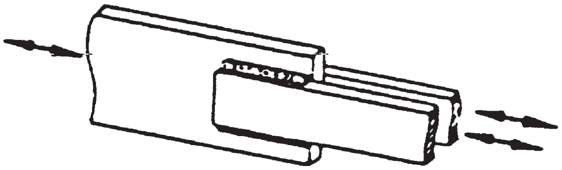

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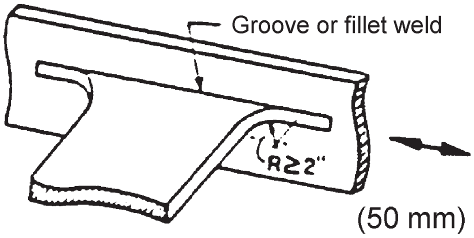

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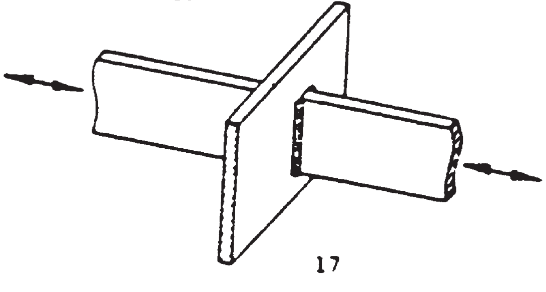

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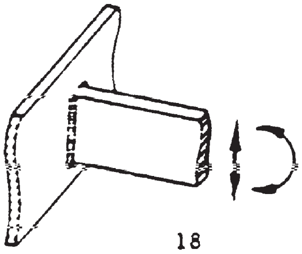

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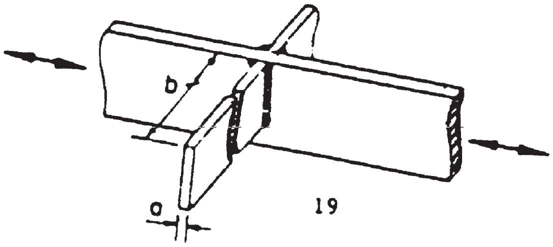

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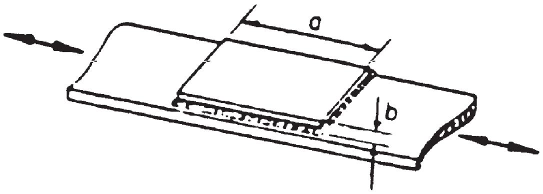

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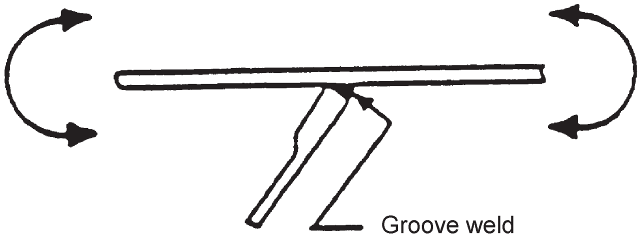

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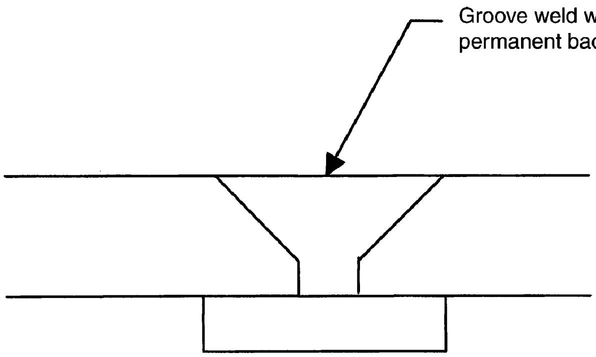

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Figure 3.1
FATIGUE DESIGN DETAILS (Continued)

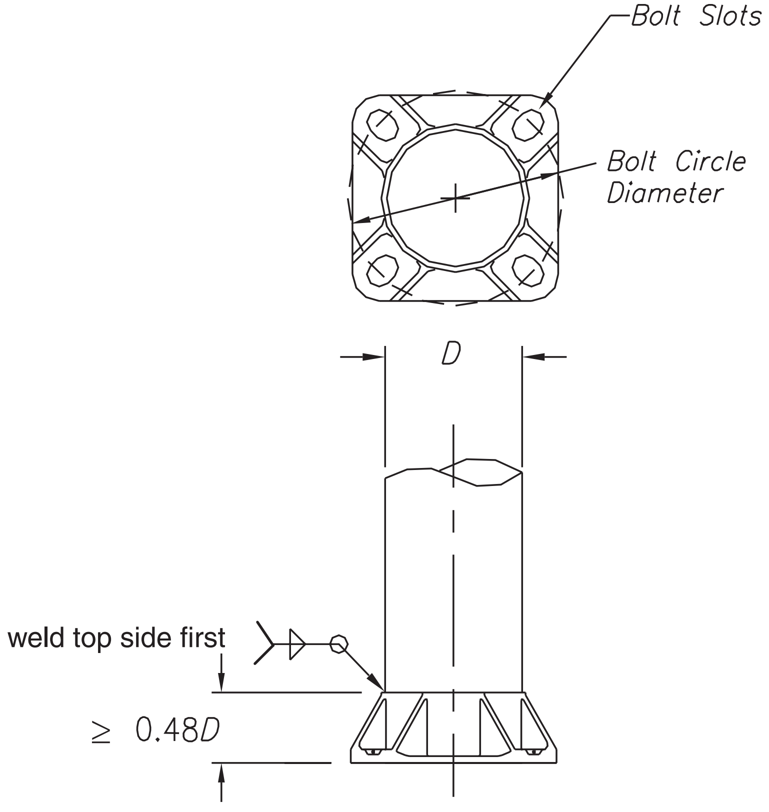

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Figure 3.1
FATIGUE DESIGN DETAILS (Continued)

Table 3.1
STRESS CATEGORY

General Condition	Detail	Detail Category	Fatigue Design Details (note 1)
Plain Material	Base metal with rolled, extruded, drawn, or cold finished surfaces; cut or sheared surfaces with ANSI/ASME B46.1 surface roughness ≤ 1000 μin. (25μmm)	A	1, 2
Built-up Members	Base metal and weld metal in members without attachments and built up of plates or shapes connected by continuous full or partial penetration groove welds or continuous fillet welds parallel to the direction of applied stress.	B	3, 4, 5
	Flexural stress in base metal at the toe of welds on girder webs or flanges adjacent to welded transverse stiffeners.	C	6, 21
	Base metal at the end of partial-length welded cover plates with square or tapered ends, with or without welds across the ends.	E	5
Mechanically Fastened Connections	Base metal at the gross section of slip-critical connections and at the net section of bearing connections, where the joint configuration does not result in out-of-plane bending in the connected material and the stress ratio (the ratio of minimum stress to maximum stress) R_S is (note 2)		
	$R_S \le 0$	B	7
	$0 < R_S < 0.5$	D	7
	$0.5 \le R_S$	E	7
	Base metal at the gross section of slip-critical connections and at the net section of bearing connections, where the joint configuration results in out-of-plane bending in connected material.	E	8
Fillet Welds	Base metal at intermittent fillet welds	E	
	Base metal at the junction of axially loaded members with fillet-welded end connections. Welds shall be disposed about the axis of the members so as to balance weld stresses.	E	15, 17
	Shear stress in weld metal of continuous or intermittent longitudinal or transverse fillet welds	F	5, 15, 18
Groove Welds	Base metal and weld metal at full-penetration groove welded splices of parts of similar cross section ground flush, with grinding in the direction of applied stress and with weld soundness established by radiographic or ultrasonic inspection.	B	9, 10
	Base metal and weld metal at full-penetration groove welded splices at transitions in width or thickness, with welds ground to slopes ≤ 1: 2.5, with grinding in the direction of applied stress, and with weld soundness established by radiographic or ultrasonic inspection.	B	11, 12
	Base metal and weld metal at full-penetration groove welded splices with or without transitions with slopes ≤ 1: 2.5, when reinforcement is not removed and/or weld soundness is not established by radiographic or ultrasonic inspection.	C	9, 10, 11, 12
	Base metal and weld metal at full-penetration groove welds with permanent backing.	E	22
Attachments	Base metal detail of any length attached by groove welds subject to transverse and/or longitudinal loading, with a transition radius $R \ge 2$ in. (50 mm) and with the weld termination ground smooth:		
	$R \ge 24$ in. (610 mm)	B	13
	24 in. $> R \ge 6$ in. (150 mm)	C	13
	6 in. $> R \ge 2$ in. (50 mm)	D	13
	Base metal at a detail attached by groove welds or fillet welds with a detail dimension parallel to the direction of stress $a < 2$ in. (50 mm)	C	19
	Base metal at a detail attached by groove welds or fillet welds subject to longitudinal loading, with a transition radius, if any, < 2 in. (50 mm):		
	2 in. (50 mm) $\le a \le 12b$ or 4 in. (100 mm)	D	14
	$a > 12b$ or 4 in. (100 mm)	E	14, 19, 20
	Base metal at a detail of any length attached by fillet welds or partial-penetration groove welds in the direction parallel to the stress, with a transition radius $R \ge 2$ in. (50 mm), and the weld termination is ground smooth:		
	$R \ge 24$ in. (610 mm)	B	16
	24 in. $> R \ge 6$ in. (150 mm)	C	16
	6 in. $> R \ge 2$ in. (50 mm)	D	16
Luminaire Base Welds	Base metal and filler metal at a pair of circumferential fillet welds at least 0.48D apart in a tube's longitudinal direction, where D = the outside diameter of the tube. Fillet welds shall be sufficient to develop the static bending strength of the tube and be placed in the following order: weld the top of the base and the tube, then weld the end of the tube and the bottom of the base. The base shall be for a top mounted luminaire or as a support for a short arm, defined as that producing no more than 5 ksi (35 MPa) tensile dead load stress in the tube at top of the base.	F1	23

Notes:
1. See Figure 3.1. These examples are provided as guidelines and are not intended to exclude other similar details.
2. Tensile stresses are considered to be positive and compressive stresses are considered to be negative.

Table 3.2
CONSTANTS FOR S-N CURVES

Detail Category	C_f		m	Constant Amplitude Fatigue Limit	
	ksi	**MPa**		**ksi**	**MPa**
A	96.5	665	6.85	10.2	70
B	130	900	4.84	5.4	37
C	278	1920	3.64	4.0	28
D	157	1080	3.73	2.5	17
E	160	1100	3.45	1.8	13
F	174	1200	3.42	1.9	13
F1	29.0	200	7.31	3.2	22

Notes:

1. Constant amplitude fatigue limit is based on $N = 5 \times 10^6$ except for detail category F1 where $N = 10 \times 10^6$.

Appendix 4 Design for Fire Conditions

This appendix addresses the design and evaluation of aluminum structures exposed to fire. It includes criteria for determining heat input, thermal expansion, and reduction in mechanical properties of aluminum at elevated temperatures.

4.1 General Provisions

Design for fire conditions shall comply with the requirements for design by engineering analysis given in Section 4.2 or the requirements for design by qualification testing given in Section 4.3. The analysis methods in Section 4.2 document the anticipated performance of aluminum structures when subjected to design-basis fires, and provide evidence of compliance with the performance objectives of Section 4.1.2. The qualification testing methods in Section 4.3 document the fire resistance of aluminum structures subject to the standardized fire testing protocols required by building codes.

4.1.1 Definitions

This appendix uses the following terms as defined below:

active fire protection: structural materials and systems activated by a fire to mitigate adverse effects or notify people to take action to mitigate adverse effects.

compartmentation: the enclosure of a structure's space with elements that have a specific fire endurance.

design-basis fire: a set of conditions that define the development of a fire and the spread of combustion products in a structure.

elevated temperatures: temperatures in excess of the anticipated ambient temperature, experienced by structural elements as a result of fire.

fire: destructive burning, as manifested by any or all of the following: light, flame, heat, or smoke.

fire barrier: an element of construction formed of fire-resisting materials and tested in accordance with ASTM E 119 or other approved standard fire-resistance test to demonstrate compliance with the building code.

fire endurance: a measure of the elapsed time during which a material or assembly continues to exhibit fire resistance.

fire resistance: the property of assemblies that prevents or retards the passage of excessive heat, hot gases, or flames under conditions of use and enables them to continue to perform a stipulated function.

flashover: the transition to a state of total surface involvement in a fire of combustible materials within an enclosure.

heat flux: radiant energy per unit surface area.

heat release rate: the rate at which thermal energy is generated by a burning material.

restrained construction: floor and roof assemblies and individual beams in buildings where the surrounding or supporting structure is capable of resisting substantial thermal expansion throughout the range of anticipated elevated temperatures.

unrestrained construction: floor and roof assemblies and individual beams in buildings that are assumed to be free to rotate and expand throughout the range of anticipated elevated temperatures.

4.1.2 Performance Objectives

Structural components, members, and frame systems shall be designed to maintain their load-bearing function during the design-basis fire and to satisfy other performance requirements specified for the building occupancy.

Deformation criteria shall be applied where the means of providing structural fire resistance or the design criteria for fire barriers requires consideration of the deformation of the load-carrying structure.

Forces and deformations from the design-basis fire shall not cause a horizontal or vertical breach of the compartment of fire origin.

4.1.3 Load Combinations and Required Strength

The required strength of the structure and its elements shall be determined using load and resistance factor design for the following gravity load combination:

$$[0.9 \text{ or } 1.2]D_n + T + 0.5L_n + 0.2S_n \tag{4-1}$$

where

D_n = nominal dead load

L_n = nominal live load

S_n = nominal snow load

T = nominal forces and deformations due to the design-basis fire defined in Section 4.2.1.

D_n, L_n, and S_n shall be the nominal loads specified in ASCE 7.

4.2 Design for Fire Conditions by Analysis

4.2.1 Design-Basis Fire

A design-basis fire shall be defined that describes heating conditions for the structure. These heating conditions shall relate to the fuel commodities and compartment characteristics present in the assumed fire area. The fuel load density based on the occupancy of the space shall be considered when determining the total fuel load. Heating conditions shall be specified in terms of a heat flux or temperature of the upper gas layer created by the fire. The variation of the heating conditions with time shall be determined for the duration of the fire.

When the analysis methods in Section 4.2 are used to demonstrate an equivalency as an alternative material or method as permitted by a building code, the design-basis fire shall be determined in accordance with ASTM E 119.

4.2.1.1 Localized Fire

Where the heat release rate from the fire is insufficient to cause flashover, a localized fire exposure shall be assumed. In such cases, the fuel composition, arrangement of the fuel, and area occupied by the fuel shall be used to determine the radiant heat flux from the flame and smoke plume to the structure.

4.2.1.2 Post-Flashover Compartment Fires

Where the heat release rate from the fire is sufficient to cause flashover, a post-flashover compartment fire shall be assumed. The determination of the temperature versus time profile resulting from the fire shall include fuel load, ventilation characteristics to the space (natural and mechanical), compartment dimensions, and thermal characteristics of the compartment boundary.

4.2.1.3 Exterior Fires

The exposure of exterior structure to flames projecting from wall openings as a result of a post-flashover compartment fire shall be considered along with the radiation from the interior fire through the opening. The shape and length of the flame projection and distance between the flame and the exterior structure shall be used to determine the heat flux to the aluminum. The method in Section 4.2.1.2 shall be used to define the interior compartment fire characteristics.

4.2.1.4 Fire Duration

The fire duration in a particular area shall be determined by considering the total combustible mass, the available fuel in the space. In the case of a localized fire or a post-flashover fire, the time duration shall be determined as the total combustible mass divided by the mass loss rate, except where determined from Section 4.2.1.2.

4.2.1.5 Active Fire Protection Systems

The effects of active fire protection systems shall be considered when defining the design-basis fire.

Where automatic smoke and heat vents are installed in non-sprinklered spaces, the resulting smoke temperature shall be determined from calculation.

4.2.2 Temperatures in Structural Systems under Fire Conditions

Temperatures within structural members, components, and frames due to heating conditions posed by the design-basis fire shall be determined by a heat transfer analysis.

4.2.3 Material Properties at Elevated Temperatures

4.2.3.1 Mechanical Properties

The deterioration in strength and stiffness of structural members shall be accounted for in the structural analysis. The modulus of elasticity at elevated temperatures E_m shall be determined from test data or Table 4.1. Yield strengths F_{tym} and ultimate strengths F_{tum} at elevated temperatures shall be determined from test data or Table 4.2.

4.2.3.2 Thermal Expansion

Thermal expansion for temperatures between 70°F and 600°F (20°C and 300°C) shall be determined using a coefficient of thermal expansion for aluminum of 14.2×10^{-6}/°F (25.6×10^{-6}/°C).

4.2.3.3 Specific Heat

The specific heat of aluminum alloys is 0.23 Btu/lb/°F (960 J/kg/°C) at 212°F (100°C).

4.2.4 Structural Design Requirements

4.2.4.1 General Structural Integrity

Structures shall provide adequate strength and deformation capacity to withstand the conditions developed during the design-basis fire within the prescribed limits of deformation. The structural system shall be designed to sustain local damage with the structural system as a whole remaining stable.

Continuous load paths shall be provided to transfer all forces from the region exposed to fire to the final point of resistance. The foundation shall be designed to resist the forces and to accommodate the deformations developed during the design-basis fire.

Table 4.1
MODULUS OF ELASTICITY AT ELEVATED TEMPERATURES

Aluminum Temperature		E_m/E
(°F)	(°C)	6xxx alloys
75	24	1.00
200	93	1.00
212	100	0.96
300	149	0.92
350	177	0.90
400	204	0.87
450	232	0.84
500	260	0.80
600	316	0.69
700	371	0.56
1000	538	0.00

Interpolate for temperatures between those given in the table.

Table 4.2
STRENGTHS AT ELEVATED TEMPERATURES

Aluminum Temperature		6061-T6		6063-T5		6063-T6	
(°F)	(°C)	F_{tym}/F_{ty}	F_{tum}/F_{tu}	F_{tym}/F_{ty}	F_{tum}/F_{tu}	F_{tym}/F_{ty}	F_{tum}/F_{tu}
75	24	1.00	1.00	1.00	1.00	1.00	1.00
200	93	1.00	1.00	1.00	1.00	1.00	1.00
212	100	0.95	0.91	0.93	0.91	0.90	0.89
300	149	0.90	0.84	0.89	0.84	0.84	0.80
350	177	0.88	0.80	0.89	0.84	0.77	0.71
400	204	0.75	0.67	0.68	0.63	0.58	0.57
450	232	0.58	0.53	0.50	0.50	0.42	0.43
500	260	0.40	0.40	0.36	0.38	0.29	0.29
600	316	0.20	0.20	0.20	0.20	0.11	0.11
700	371	0.08	0.08	0.08	0.08	0.06	0.07
1000	538	0.00	0.00	0.00	0.00	0.00	0.00

Interpolate for temperatures between those given in the table.

4.2.4.2 Strength Requirements and Deformation Limits

Conformance of the structural system to these requirements shall be demonstrated by constructing a mathematical model of the structure based on principles of structural mechanics and evaluating this model for the internal forces and deformations in the members of the structure developed by the temperatures of the design-basis fire.

Individual members shall be provided with adequate strength to resist the shears, axial forces, and moments determined by this analysis.

Connections shall develop the strength of the connected members or the forces indicated above. Where the means of providing the fire resistance requires the consideration of deformation criteria, the deformation of the structural system or members thereof under the design-basis fire shall not exceed the prescribed limits.

4.2.4.3 Methods of Analysis

4.2.4.3.1 Advanced Methods of Analysis

The methods of analysis in this section are permitted for the design of all aluminum structures for fire conditions. The design-basis fire exposure shall be that determined in Section 4.2.1. The analysis shall include both a thermal response and the mechanical response to the design-basis fire.

The thermal response shall produce a temperature field in each structural element as a result of the design-basis fire and shall incorporate temperature-dependent thermal properties of the structural elements and fire-resistive materials in accordance with Section 4.2.2.

The mechanical response results in forces and deformations in the structural system subjected to the thermal response calculated from the design-basis fire. The mechanical response shall explicitly account for the deterioration in strength and stiffness with increasing temperature, the effect of thermal expansion, and large deformations. Boundary conditions and connection fixity in the analysis shall be representative of the proposed structural design. Material properties shall be as given in Section 4.2.3.

The resulting analysis shall consider all relevant limit states, such as excessive deflections, connection fractures, and overall and local buckling.

4.2.4.3.2 Simple Methods of Analysis

The methods of analysis in this section apply to evaluating the performance of individual members at elevated temperatures during exposure to fire.

Support and restraint conditions (forces, moments, and boundary conditions) at normal temperatures may be assumed to remain unchanged throughout the fire exposure.

1) Tension members
   It is permitted to model the thermal response of a tension member using a one-dimensional heat transfer equation with heat input from the design-basis fire defined in Section 4.2.1.

   The design strength of a tension member shall be determined using the provisions of Chapter D with aluminum properties as given in Section 4.2.3 and assuming a uniform temperature over the cross section using the temperature equal to the maximum aluminum temperature.

2) Compression members
   It is permitted to model the thermal response of a compression member using a one-dimensional heat transfer equation with heat input from the design-basis fire defined in Section 4.2.1.

   The design strength of a compression member shall be determined using the provisions of Chapter E with aluminum properties as given in Section 4.2.3.

3) Flexural members

It is permitted to model the thermal response of a flexural member using a one-dimensional heat transfer equation to calculate bottom flange temperature and to assume that this bottom flange temperature is constant over the depth of the member. Heat input shall be determined from the design-basis fire defined in Section 4.2.1.

The design strength of a flexural member shall be determined using the provisions of Chapter F with aluminum properties as given in Section 4.2.3.

4.2.4.4 Design Strength

The design strength shall be determined in accordance with Section B.3. The nominal strength R_n shall be determined using the material properties given in Section 4.2.3 at the temperature developed during the design-basis fire.

4.3 Design by Qualification Testing

4.3.1 Qualification Standards

Structural members and components in aluminum structures shall be qualified for the rating period in conformance with ASTM E 119.

4.3.2 Restrained Construction

A restrained condition exists when the surrounding or supporting structure is capable of resisting actions caused by thermal expansion throughout the range of anticipated elevated temperatures.

Appendix 5 Evaluation of Existing Structures

5.1 General Provisions

These provisions apply to evaluating the strength or serviceability of existing members, connections, or structures. Evaluations shall be performed by structural analysis or both structural analysis and load testing.

5.2 Material Properties

5.2.1 Wrought and Cast Products

Unless the aluminum alloy and temper used in the structure are identified from records, specimens shall be cut from the structure and both:

a) Chemical composition tests shall be conducted to determine the alloy, and
b) Tensile tests shall be conducted in accordance with ASTM B 557 to determine the tensile yield strength, tensile ultimate strength, and elongation to determine the temper.

Mechanical properties given in the appropriate ASTM material specification for the alloy, temper, and product that were determined to have been used in the structure shall be used in the structural analysis.

5.2.2 Welds

Where structural performance depends on existing welds:

a) The filler metals used in the structure shall be identified from records or chemical analysis of representative samples of weld metal.
b) If welds do not meet the visual inspection criteria of AWS D1.2, additional inspection shall be conducted to determine their strength.

5.2.3 Bolts and Rivets

Unless bolt or rivet strength can be determined from records or markings, representative samples shall be removed and tested to determine tensile strength in accordance with ASTM F 606 or ASTM F 606M.

5.3 Evaluation by Structural Analysis

5.3.1 Dimensions

Dimensions and the condition of structural members and connections shall be determined from records and/or from a field survey.

5.3.2 Strength Evaluation

Loads shall be determined in accordance with Section B.2 or the maximum load that can be withstood shall be determined. Load effects in the structure shall be detemined by structural analysis. The strength of members and connections shall be determined using the *Specification for Aluminum Structures.*

5.3.3 Serviceability Evaluation

Deformations shall be calculated at service loads.

5.4 Evaluation by Load Testing

To prevent excessive permanent deformation or collapse during load testing, the structure shall be analyzed and a written testing plan prepared before testing.

Test loads shall be applied incrementally in accordance with the written testing plan. Test loads shall not exceed a factored load of $1.0D_n + 1.4L_n$. The structure shall be visually inspected for signs of distress or imminent failure at each load increment. Deformations shall be recorded at each load increment and one hour and 24 hours after the removal of the load.

5.5 Evaluation Report

The evaluation shall be documented by a written report that includes:

a) whether the evaluation was performed by structural analysis or a combination of structural analysis and load testing;
b) when testing is performed, the loads and load combinations used and the load-deformation and time-deformation relationships observed;
c) information obtained from records and material testing;
d) the allowable strength or design strength of the structure; and
e) the date the evaluation was performed.

Appendix 6 Design of Braces for Columns and Beams

This appendix addresses strength and stiffness requirements for braces for columns and beams.

6.1 General Provisions

The available strength and stiffness of bracing members and connections shall equal or exceed the required strength and stiffness, respectively, given in this appendix.

Columns with end and intermediate braced points that meet the requirements of Section 6.2 shall be designed using an unbraced length L equal to the distance between the braced points with an effective length factor $k = 1.0$. Beams with intermediate braced points that meet the requirements of Section 6.3 shall be designed using an unbraced length L_b equal to the distance between the braced points.

As an alternate to the requirements of Sections 6.2 and 6.3, a second-order analysis that includes initial out-of-straightness of the member to be braced shall be used to obtain the brace strength and stiffness requirements.

For all braces, $\phi = 0.75$ (LRFD), and $\Omega = 2.00$ (ASD), except that for nodal torsional bracing of beams, $\Omega = 3.00$.

6.1.1 Bracing Types

a) A relative brace controls movement of the braced point with respect to adjacent braced points.
b) A nodal brace controls movement of the braced point without direct interaction with adjacent braced points.
c) Continuous bracing is bracing attached along the entire member length.

6.1.2 Bracing Orientation

The brace strength (force or moment) and stiffness (force per unit displacement or moment per unit rotation) requirements given in this appendix are perpendicular to the member braced. The available brace strength and stiffness perpendicular to the member braced for inclined braces shall be adjusted for the angle of inclination. The determination of brace stiffness shall include the effects of member properties and connections.

6.2 Column Bracing

6.2.1 Relative Bracing

The required strength is

$$P_{rb} = 0.004P_r \qquad (6\text{-}1)$$

The required stiffness is

$$\beta_{br} = \frac{1}{\phi}\left(\frac{2P_r}{L_b}\right) \qquad \text{(LRFD)} \qquad (6\text{-}2)$$

$$\beta_{br} = \Omega\left(\frac{2P_r}{L_b}\right) \qquad \text{(ASD)} \qquad (6\text{-}2)$$

where

L_b = distance between braces

For LRFD,
P_r = required axial compression strength using LRFD load combinations.

For ASD,
P_r = required axial compression strength using ASD load combinations.

6.2.2 Nodal Bracing

For nodal braces equally spaced along the column:

The required strength is

$$P_{rb} = 0.01P_r \qquad (6\text{-}3)$$

The required stiffness is

$$\beta_{br} = \frac{1}{\phi}\left(\frac{8P_r}{L_b}\right) \qquad \text{(LRFD)} \qquad (6\text{-}4)$$

$$\beta_{br} = \Omega\left(\frac{8P_r}{L_b}\right) \qquad \text{(ASD)} \qquad (6\text{-}4)$$

where

L_b = distance between braces. In Equation 6-4, L_b need not be taken less than the maximum unbraced length kL permitted for the column based on the required axial strength P_r.

For LRFD,
P_r = required axial compression strength using LRFD load combinations.

For ASD,
P_r = required axial compression strength using ASD load combinations.

6.3 Beam Bracing

Beams and trusses shall be restrained against rotation about their longitudinal axis at support points. Beam bracing shall prevent relative displacement of the top and bottom flanges (twist of the section). Lateral stability of beams shall be provided by lateral bracing, torsional bracing, or a combination of the two. Inflection points shall not be considered braced points unless they are provided with braces meeting the requirements of this appendix.

6.3.1 Lateral Bracing

Lateral braces shall be attached at or near the compression flange, except:

a) At the free end of cantilever members, lateral braces shall be attached at or near the tension flange.
b) For beams subjected to double curvature bending, lateral bracing shall be attached to both flanges at the brace point nearest the inflection point.

6.3.1.1 Relative Bracing

The required strength is

$$P_{rb} = 0.008M_rC_d/h_o \tag{6-5}$$

The required stiffness is

$$\beta_{br} = \frac{1}{\phi}\left(\frac{4M_rC_d}{L_bh_o}\right) \quad \text{(LRFD)} \tag{6-6}$$

$$\beta_{br} = \Omega\left(\frac{4M_rC_d}{L_bh_o}\right) \quad \text{(ASD)} \tag{6-6}$$

where

h_o = distance between flange centroids
C_d = 1.0 except $C_d = 2.0$ for the brace closest to the inflection point in a beam subject to double curvature
L_b = distance between braces

For LRFD,
M_r = required flexural strength using LRFD load combinations.

For ASD,
M_r = required flexural strength using ASD load combinations.

6.3.1.2 Nodal Bracing

The required strength is

$$P_{rb} = 0.02M_rC_d/h_o \tag{6-7}$$

The required stiffness is

$$\beta_{br} = \frac{1}{\phi}\left(\frac{10M_rC_d}{L_bh_o}\right) \quad \text{(LRFD)} \tag{6-8}$$

$$\beta_{br} = \Omega\left(\frac{10M_rC_d}{L_bh_o}\right) \quad \text{(ASD)} \tag{6-8}$$

where

h_o = distance between flange centroids
C_d = 1.0 except $C_d = 2.0$ for the brace closest to the inflection point in a beam subject to double curvature
L_b = distance between braces. In Equation 6-8, L_b need not be taken less than the maximum unbraced length permitted for the beam based on the required flexural strength M_r.

For LRFD,
M_r = required flexural strength using LRFD load combinations.

For ASD,
M_r = required flexural strength using ASD load combinations.

6.3.2 Torsional Bracing

Bracing shall be attached to the braced member at any cross section location on the member and need not be attached near the compression flange.

6.3.2.1 Nodal Bracing

The required strength is

$$M_{rb} = \frac{0.024M_rL}{nC_bL_b} \tag{6-9}$$

The required stiffness of the brace is

$$\beta_{Tb} = \frac{\beta_T}{\left(1 - \dfrac{\beta_T}{\beta_{sec}}\right)} \tag{6-10}$$

If $\beta_{sec} < \beta_T$, torsional beam bracing shall not be used.

$$\beta_T = \frac{1}{\phi}\left(\frac{2.4LM_r^2}{nEI_yC_b^2}\right) \quad \text{(LRFD)} \tag{6-11}$$

$$\beta_T = \Omega\left(\frac{2.4LM_r^2}{nEI_yC_b^2}\right) \quad \text{(ASD)} \tag{6-11}$$

$$\beta_{sec} = \frac{3.3E}{h_o}\left(\frac{1.5h_ot_w^3}{12} + \frac{t_sb_s^3}{12}\right) \tag{6-12}$$

where

L = span length. In Equation 6-9, L_b need not be taken less than the maximum unbraced length permitted for the beam based on the required flexural strength M_r.
n = number of nodal braced points in the span
I_y = out-of-plane moment of inertia
C_b = beam coefficient determined in accordance with Section F.1.1
t_w = beam web thickness
t_s = beam web stiffener thickness
b_s = stiffener width for one-sided stiffeners (use twice the individual width for pairs of stiffeners)
β_T = overall brace system stiffness

β_{sec} = web distortional stiffness, including the effect of web transverse stiffeners, if any

For LRFD,
M_r = required flexural strength using LRFD load combinations.

For ASD,
M_r = required flexural strength using ASD load combinations.

Web stiffeners shall extend the full depth of the braced member and shall be attached to the flange if the torsional brace is also attached to the flange. Alternatively, the stiffener may end a distance of $4t_w$ from any beam flange that is not directly attached to the torsional brace.

6.3.2.2 Continuous Bracing

For continuous bracing, use Equations 6-9 and 6-10 with the following modifications:

a) $L/n = 1.0$;
b) L_b shall be taken as the maximum unbraced length permitted for the beam based on the required flexural strength M_r;
c) The web distortional stiffness shall be taken as:

$$\beta_{sec} = \frac{3.3Et_w^3}{12h_o} \tag{6-13}$$

6.4 Beam-Column Bracing

For beam-columns, the required strength and stiffness for axial force shall be determined as specified in Section 6.2, and the required strength and stiffness for flexure shall be determined as specified in Section 6.3. The values so determined shall be combined as follows:

a) When relative lateral bracing is used, the required strength is the sum of the values determined using Equations 6-1 and 6-5, and the required stiffness is the sum of the values determined using Equations 6-2 and 6-6.
b) When nodal lateral bracing is used, the required strength is the sum of the values determined using Equations 6-3 and 6-7, and the required stiffness is the sum of the values determined using Equations 6-4 and 6-8. In Equations 6-4 and 6-8, L_b for beam columns shall be taken as the actual unbraced length; the provisions in Sections 6.2.2 and 6.3.1.2 that L_b need not be taken less than the maximum permitted unbraced length based upon P_r and M_r shall not be applied.
c) When torsional bracing is provided for flexure in combination with relative or nodal bracing for the axial force, the required strength and stiffness shall be combined or distributed in a manner consistent with the resistance provided by the element(s) of the actual bracing details.

Aluminum Design Manual

PART II

Specification for Aluminum Structures
Commentary

II
Specification for Aluminum Structures Commentary

TABLE OF CONTENTS

Chapter A General Provisions

A.1 Scope

This *Specification* replaces the 2005 *Specification for Aluminum Structures—Allowable Stress Design* and the 2005 *Specification for Aluminum Structures—Building Load and Resistance Factor Design,* and its organization is similar to the 2010 AISC *Specification for Structural Steel Buildings.*

This *Specification* provides the nominal strength of aluminum structures, members, and connections. The nominal strength is usually defined as a force or moment, but in some cases as a stress.

This *Specification* provides two methods of design:

1) Load and Resistance Factor Design (LRFD): The nominal strength multiplied by a resistance factor must equal or exceed the required strength determined by analysis for the appropriate LRFD load combinations. This *Specification* provides resistance factors for building-type structures;
2) Allowable Strength Design (ASD): The nominal strength divided by a safety factor must equal or exceed the required strength determined by analysis for the appropriate ASD load combinations. This *Specification* provides safety factors for building-type structures and bridge-type structures.

A.2 Referenced Documents

This section lists the referenced documents and establishes the editions of the documents to be used with this *Specification.*

A.3 Material

A.3.1 General Properties

More precise densities and coefficients of thermal expansion than those given in this Section are given in the *Aluminum Design Manual* Part IV Tables 7 and 8, respectively, and in *Aluminum Standards and Data.*

The shear yield strength F_{sy} is based on the von Mises yield criterion that $F_{sy} = F_{ty}/\sqrt{3}$, approximated as $F_{sy} = 0.6\ F_{ty}$.

A.3.1.1 Mechanical Properties

For the alloys included in this *Specification,* mechanical properties are negligibly affected at temperatures up to 200°F. The *Aluminum Design Manual* Part IV Table 9 and Kaufman (1999) provide typical mechanical properties for many aluminum products at elevated temperatures. The reduction in strength varies with alloy, temper, temperature, and time of exposure.

Because the reduction in strength will not exceed 5% for the alloys, tempers, times, and temperatures given in Table A.3.2, it is unnecessary to account for this reduction in design within these limits.

A.3.1.2 Temperature Limits

See the commentary to Section M.3.

A.3.1.3 Tension Coefficient k_t

The notch strength is the ultimate tensile strength of a standard notched specimen. Kaufman (2001) documented the notch strength of a number of aluminum alloy-tempers and suggested ASTM tests for determining notch strength.

Alloy-tempers with notch-strength-to-yield-strength ratios less than 1 are considered to be notch sensitive, since they will rupture at a notch before yielding. Such alloy-tempers require a reduction in the tensile ultimate strength used for design. This reduction is made by dividing the tensile ultimate strength by the tension coefficient k_t, a coefficient greater than or equal to 1.

The k_t factor of 1.25 for 2014-T6 has been used since publication of ASCE (1956).

The k_t factor of 1.25 for 6005-T5 and 6105-T5 is based on the fact that Kaufman (2001) shows that the unit propagation energy for 6005-T5 is no greater than that for 2014-T6.

A.3.2 Wrought Products

Table A.3.4 tensile ultimate strengths F_{tu} and tensile yield strengths F_{ty} are specified strengths (Aluminum Association (2009)) except F_{ty} for 1100-H12 and H14 rod and bar and drawn tube, Alclad 3003-H18 sheet, and 5050-H32 and H34 rod and bar, which are expected strengths, explained in the next paragraph. Specified strengths are established after sufficient test data have been accumulated to determine the form of the frequency distribution curve and to provide a reliable estimate of the population mean and standard deviation. In most instances the distribution is normal and strengths are based on the results of at least 100 tests from at least 10 different lots of material. Tensile strengths are established at levels at which 99% of the material is expected to conform at a 0.95 confidence level.

Table A.3.4 compressive yield strengths F_{cy} and shear ultimate strengths F_{su} are expected strengths that 99% of the population is expected, but not guaranteed, to equal or exceed. Material should not be accepted or rejected based on these strengths. These strengths are derived strengths established by multiplying strengths from tests of representative lots of material by the ratio of the specified tensile yield or ultimate strength to the tensile yield or ultimate strength of the lot tested. Effort is made to base these strengths on test results for at least 5 lots of each alloy, temper, and product, but there are instances where insufficient data are available and the strengths are based on data for similar products.

Test methods used to determine mechanical properties are summarized below:

Type of Stress	**ASTM Test Method**
Tension	B 557
Compression	E 9
Shear	B 769

The compressive modulus of elasticity E given in Table A.3.4 is a typical value. The tensile modulus of elasticity is approximately 2% less than the compressive modulus.

Aluminum alloys gain strength by heat treatment or strain hardening. Welding causes local annealing, which erases this strength increase in a zone along both sides of the weld. The resulting variation in mechanical properties in the vicinity of a weld is illustrated by the typical distribution in Figure CA.3.1. Moore, et al. (1971) discussed the effect of welding heat on aluminum mechanical properties.

Table A.3.5 gives the welded strengths for weldments produced in accordance with AWS D1.2. The welded tensile ultimate strengths F_{tuw} are the weld qualification strengths required by AWS D1.2. Welded yield strengths are for 0.2% offset in a 2 in. (50 mm) gauge length. The 2 in. gauge length is centered on a transverse groove-welded specimen. Since the heat-affected zone extends approximately 1 in. from the center of a weld, the full specimen is heat-affected and thus representative of welded material.

Welded compressive yield strengths F_{cyw} and welded shear ultimate strengths F_{suw} are derived from the relationships among those properties of the base metal alloy/temper products. For non-heat treatable alloys, the welded tensile ultimate strengths F_{tuw} and welded tensile yield strengths F_{tyw} are the strengths for the annealed temper (O) of the alloy, and for heat treatable alloys, the welded tensile ultimate and tensile yield strengths are slightly less than the solution heat treated (T4 temper) strengths (Nelson and Howell (1952)). For heat treatable alloys, the welded tensile ultimate and welded tensile yield strengths are based on statistical analysis of test data where possible, and are the strengths that 99% of the population would be expected to equal or exceed with a confidence level of 0.75. Where insufficient data are available, welded strengths are based on data for combinations of similar filler and base metal.

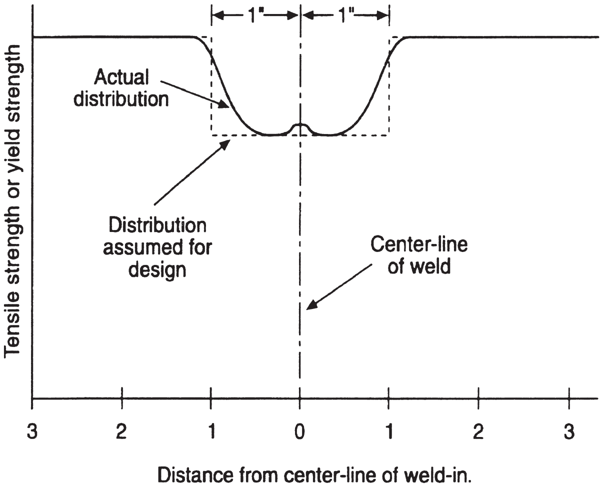


Figure CA.3.1
DISTRIBUTION OF MECHANICAL PROPERTIES NEAR A WELD

A.3.3 Castings

ASTM B 26 and B 108 do not specify tensile yield strengths for some of the cast alloy-tempers they include (for example, sand cast 356.0-T7). These alloy-tempers are not included in Table A.3.6 (and therefore are excluded from the scope of this *Specification*) since design usually uses the yield strength. There are also other alloy-tempers in B 26 or B 108 that are not included in Table A.3.6 and therefore not included in this *Specification.*

ASTM B 26 and B 108 do not require conformance with dimensional standards (tolerances) as do ASTM specifications for wrought products (for example, B 209). Therefore, dimensional standards for castings are established in this *Specification* as those in the Aluminum Association *Standards for Aluminum Sand and Permanent Mold Castings.*

The strengths specified in ASTM B 26 Table 2 for sand castings are for separately cast test bars and not for the castings themselves. Section 11.3 of ASTM B 26 states "When specified, the tensile strength, yield strength, and elongation values of specimens cut from castings shall not be less than 75% of the tensile and yield strength values and not less than 25% of the elongation values specified in Table 2." Therefore, the strengths given in Table A.3.6 are based on 75% of the ASTM B 26 Table 2 strengths to represent what a purchaser would expect to receive if he requires testing of the actual castings.

Castings are more prone to discontinuities than wrought products. Therefore, this *Specification* includes discontinuity standards for castings in order for them to be designed to the same *Specification* provisions as wrought products. The quality standards are based on the following:

ASTM B 26 and B 108 (section 20) both include options for liquid penetrant and radiographic inspection that may be specified by the purchaser. Liquid penetrant inspection detects only surface flaws, so it is insufficient. ASTM B 26 and B 108 only require radiographic inspection be performed if the purchaser specifies such inspection. If such inspection is specified, the purchaser must also specify which of four quality grades (A, B, C, or D) must be met. Grade A allows no discontinuities at all; this is more stringent than wrought product quality levels and so it is unwarranted. When Grade D is specified, no tensile tests of coupons cut from castings are required. Therefore, only grade B or C are suitable for the type of structural components addressed by this *Specification.* Grade C is used, since Grade C allows gas holes no larger than approximately 1/8 in. and this is the same as the ultrasonic inspection Grade B flaw size limit for wrought plate in *Aluminum Standards and Data* (Table 6.3).

Once the acceptance criteria for an individual casting are determined, the number of castings from a given lot to be radiographed and the acceptance criteria for the lot must be established. *Standards for Aluminum Sand and Permanent Mold Castings* establishes four frequency levels for inspection, Level 1 requiring the most frequent inspection (radiographing every casting). Inspection Level 2 requires a statistically determined frequency of sampling and is used in this *Specification.* Level 3 leaves the inspection frequency up to the foundry and Level 4 requires no radiographs; therefore, neither requires inspection.

Strengths given in Table A.3.6 and Table A.3.6M are taken from ASTM B 26 for sand castings and B 108 for permanent mold castings. B 26 allows the purchaser to require that the strength of coupons cut from production castings be no less than 75% of the specified strength, so the values in Table A.3.6 are the B 26 values factored by 0.75. B 108 has the same requirement, but for certain alloy-tempers allows the purchaser to specify either 1) locations in the casting that shall have certain B 108-specified tensile strengths; or 2) that any location in the casting shall have certain B 108-specified tensile strengths. The strengths for case 2) are usually lower than those for case 1). For both cases 1) and 2), the strengths in Table A.3.6 are the B 108-specified strengths without any factors.

Kaufman (2001) Figure 5.4 provides notch-strength-to-yield-strength ratios for various sand and permanent mold alloy/temper products. The alloy/temper products in this *Specification* have notch-yield ratios ≥ 1.0, so no reduction in tensile fracture strength is required for notch sensitivity for these alloy-tempers and the tension coefficient k_t is 1.0.

A.3.4 Filler Metal for Welding

This *Specification* and AWS D1.2 require that weld filler metal comply with AWS A5.10. Tables M.9.1 and M.9.2 show the appropriate filler alloy for various base metal combinations.

A.3.5 Bolts and Nuts

This *Specification* addresses only aluminum bolts.

A.3.6 Rivets

This *Specification* addresses only aluminum rivets.

A.3.7 Screws

This *Specification* addresses only aluminum screws. There are no ASTM specifications for aluminum screws.

Chapter B Design Requirements

B.1 Section Properties

Section properties for many shapes are given in this *Manual* in Part V. Formulas for calculating section properties are also given in Part V.

Nominal (rather than minimum) dimensions are used to calculate section properties. This is because safety or resistance factors account for the fact that actual dimensions may be less than nominal dimensions, within the tolerances prescribed by the material specifications required by Section A.3.

The torsion constant J may be determined as follows:

a) For open shapes $J = \Sigma\,(1/3 - 0.2t/b)bt^3$ for the rectangles comprising the shape where b is the larger dimension and t is the smaller dimension of each rectangle. The term for rectangles with $b/t > 10$ may be approximated by $bt^3/3$.

b) For closed shapes of uniform thickness, $J = \dfrac{4A_m^2 t}{s}$ where A_m = the mean of the areas between the inner and outer boundaries, s is the length of the boundary at mid-thickness, and t is the boundary thickness.

For rectangular tubes with side dimension a with thickness t_1 and side dimension b with thickness t_2 (see Figure CB.1.1)

$$J = \frac{2t_2t_1(a - t_2)^2\,(b - t_1)^2}{t_2(a - t_2) + t_1(b - t_1)}$$

If $t_1 = t_2 = t$, $J = \dfrac{2t(a - t)^2\,(b - t)^2}{a + b - 2t}$.

c) For shapes containing open parts and closed parts, J is the sum of J for the open parts and J for the closed parts.

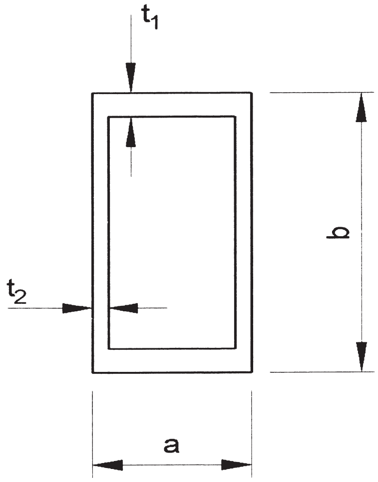


Figure CB.1.1
CROSS-SECTIONAL NOTATION

B.2 Loads and Load Combinations

B.2.1 Building-Type Structures

For building-type structures, ASCE 7 Section 2.3 provides LRFD load combinations and ASCE 7 Section 2.4 provides ASD load combinations.

B.2.2 Bridge-Type Structures

Aluminum highway bridges may also be designed using AASHTO (1991) for ASD and AASHTO (1998) for LRFD.

B.2.3 Other Structures

Loads for structures other than building- and bridge-type structures may be determined from specifications that address such structures. For example, AASHTO's *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (2009) may be used to determine the loads for structures within its scope.

B.3 Design Basis

Load and Resistance Factor Design (LRFD) and Allowable Strength Design (ASD) are equally acceptable in this *Specification.*

B.3.1 Limit States

A limit state is a condition in which a structure or component is judged to be no longer useful for its intended service (serviceability limit state) or to have reached its ultimate load-carrying capacity (strength limit state). An example of a serviceability limit state is a deflection beyond which the structure is unfit for service. An example of a strength limit state is member buckling of a column.

B.3.2 Required Strength

This *Specification* permits the use of elastic analysis only in determining required strengths.

B.3.2.1 Design for Strength Using Load and Resistance Factor Design (LRFD)

Design by LRFD requires that equation B.3-1 be satisfied; that is, the required strength determined from the LRFD load combinations does not exceed the design strength.

The design strength ϕR_n is the product of the resistance factor ϕ and the nominal strength R_n. Resistance factors are less than or equal to 1.0 and account for unavoidable deviations of the actual strength from the nominal strength and for the manner and consequence of failure.

The basis for load and resistance factor design is given by Ellingwood, et al. (1982). The resistance of the structure R and the load effect Q are modeled as statistically independent random quantities as shown in Figure CB.3.1.

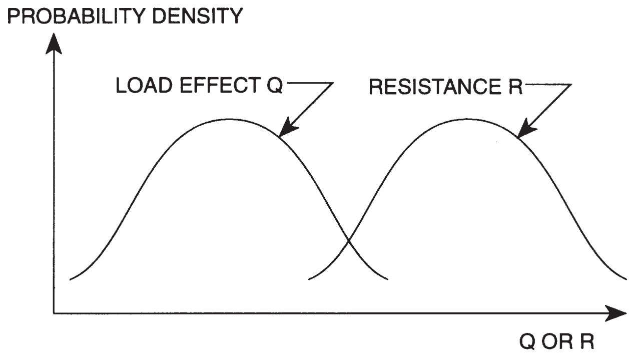


Figure CB.3.1
SCHEMATIC REPRESENTATION OF PROBABILITIES OF THE LOAD EFFECT AND THE RESISTANCE

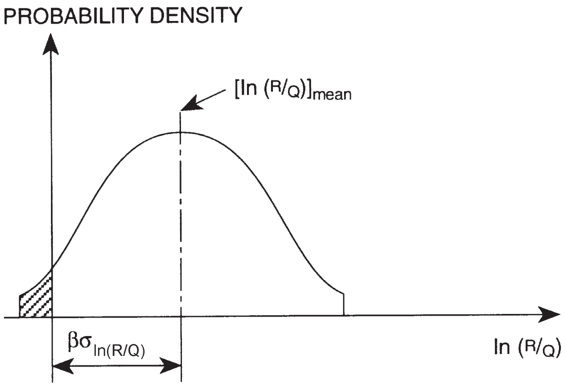


Figure CB.3.2
DEFINITION OF THE RELIABILITY INDEX ß

Failure occurs when the resistance *R* is less than the load effect *Q;* the probability of this occurring is represented by the overlap between the two curves in Figure CB.3.1. This probability is a function of the difference between mean value of the resistance and the mean value of the load effect and the distribution shapes of the *R* and *Q* curves.

Failure can also be defined as $\ln(R/Q) < 0$. In Figure CB.3.2, failure is represented by the shaded area. The reliability index β is given by

$$\beta = \frac{\ln(R_m/Q_m)}{\sqrt{V_R^2 + V_Q^2}}$$

where R_m = mean value of resistance
Q_m = mean value of load effect
V_R = coefficient of variation of resistance
V_Q = coefficient of variation of load effect.

Galambos (1979) determined the reliability index for limit states in the *Specifications for Aluminum Structures.* His work is summarized in Tables CB.3.1, CB.3.2, and CB.3.3.

Resistance factors in this *Specification* were chosen to achieve similar levels of safety and reliability for ASD and LRFD. To do so, the relationship between safety factors and resistance factors can be established as follows:

For ASD: $R_n / \Omega = D + L$
For LRFD: $\phi R_n = AD + BL$

where A = dead load factor = 1.2
B = live load factor = 1.6.

Solving for ϕ

$$\phi = [A(D/L) + B] / [\Omega(1 + D/L)]$$

Table CB.3.4 shows that for *D/L* ratios of about 0.5 or less, resistance factors of 0.75 for rupture, 0.90 for all other member limit states, 0.65 for bolt or rivet failure, and 0.5 for screw failure are no less conservative than ASD; therefore, this *Specification* uses these resistance factors. This matches the 2005 AISC *Specification* for rupture and other member limit states.

B.3.2.2 Design for Strength using Allowable Strength Design (ASD)

The *Specification for Aluminum Structures* has historically used a safety factor of 1.65 on yield and beam buckling limit states and 1.95 on tensile rupture limit states, and those are used in this edition of the *Specification.*

The safety factor for column member buckling in this *Specification* has effectively been 1.65, since a safety factor of 1.95 was prescribed without applying a factor for out-of-straightness, which is approximately 0.85 (1.95 × 0.85 = 1.65). Because a column out-of-straightness factor of 0.85 is applied in this edition of the *Specification,* the safety factor for column member buckling is set at 1.65.

The safety factor for column local buckling has been changed in this edition of the *Specification* from 1.95 to 1.65 to be consistent with the safety factor for beam local buckling. An out-of-straightness factor has not been applied to local buckling because the local buckling strength is not sensitive to out-of-straightness (Sharp (1993)).

B.4 Buckling Constants

The buckling constants given in Section B.4 are used to determine inelastic buckling strengths and reflect the tangent modulus of elasticity in the inelastic range, as documented by Clark and Rolf (1966). The stress-strain curve for artificially aged tempers (those beginning with T5, T6, T7, T8, or T9) has a different shape after yield than that for non-artificially aged tempers (those beginning with O, H, T1, T2, T3, or T4). Therefore, different buckling constant formulae are used for artificially aged tempers than those used for non-artificially aged tempers.

Table CB.3.1
SUMMARY OF RELIABILITY INDEX STATISTICAL DATA

Sec 3.4.*	Limit State	*SF*	P_m	M_m	F_m	R_m/R_n	V_P	V_M	V_F	V_R	*Category*
1,2,3,4	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	A
1,2,3,4	U	1.95	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	B
8,9	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
8,9	B	1.95	1.0	1.0	1.0	1.0	0.05	0.06	0.05	0.09	D
10	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
10	IB	1.95	1.0	1.0	1.0	1.0	0.05	0.06	0.05	0.09	D
10	EB	1.95	1.24	1.0	1.0	1.24	0.27	0.06	0.05	0.28	E
11,13,14	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
11,13,14	B	1.65	1.03	1.0	1.0	1.03	0.11	0.06	0.05	0.13	F
12,16.1	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
12,16.1	IB	1.65	1.01	1.0	1.0	1.01	0.05	0.06	0.05	0.09	G
12,16.1	EB	1.65	1.24	1.0	1.0	1.24	0.27	0.06	0.05	0.28	H
15,16,17	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
15,16,17	B	1.65	1.0	1.0	1.0	1.0	0.05	0.06	0.05	0.09	I
20	Y	1.65	1.0	1.10	1.0	1.10	0	0.06	0.05	0.08	C
20	IB	1.65	1.07	1.0	1.0	1.07	0.09	0.06	0.05	0.12	J
20	EB	1.65	0.93	1.0	1.0	0.93	0.09	0.06	0.05	0.12	K

*Section number in *Specification for Aluminum Structures, 2005.*

Notes:

1. Limit states are: Y = yield; U = tensile rupture; B = buckling; IB = inelastic buckling; EB = elastic buckling.
2. Parameters are:

SF = safety factor
P_m = mean value of the ratio of actual strength to theoretical strength
M_m = mean value of the ratio of material strength to specified material strength
F_m = mean value of the ratio of fabricated dimensions to nominal dimensions
$R_m/R_n = P_m M_m F_m$
V_P = coefficient of variation of the ratio of actual strength to theoretical strength
V_M = coefficient of variation of the ratio of material strength to specified material strength
V_F = coefficient of variation of the ratio of fabricated dimensions to nominal dimensions
$V_R = \sqrt{V_P^2 + V_M^2 + V_F^2}$.

Table CB.3.2
LIMIT STATE CATEGORIES

Category	*SF*	R_m/R_n	V_R	Description
A	1.65	1.10	0.08	yield in tension
B	1.95	1.10	0.08	rupture in tension
C	1.65	1.10	0.08	yield in compression
D	1.95	1.00	0.09	local buckling in columns
E	1.95	1.24	0.28	elastic local buckling of curved elements in compression
F	1.65	1.03	0.13	lateral torsional buckling of beams
G	1.65	1.01	0.09	inelastic local buckling of curved elements in bending
H	1.65	1.24	0.28	elastic local buckling of curved elements in bending
I	1.65	1.00	0.09	local buckling in beams
J	1.65	1.07	0.12	inelastic shear buckling
K	1.65	0.93	0.12	elastic shear buckling

Table CB.3.3
RELIABILITY INDICES

Category	β for $D/L = 0.1$	β for $D/L = 0.2$	Description
A	2.46	2.64	yield in tension
B	3.16	3.40	rupture in tension
C	2.87	3.09	yield in compression
D	2.72	2.92	local buckling in columns
E	2.44	2.51	elastic local buckling of curved elements in compression
F	2.01	2.13	lateral torsional buckling of beams
G	2.08	2.22	inelastic local buckling of curved elements in bending
H	1.98	2.03	elastic local buckling of curved elements in bending
I	2.04	2.18	local buckling in beams
J	2.20	2.34	inelastic shear buckling
K	1.65	1.75	elastic shear buckling

Table CB.3.4
RELATING RESISTANCE FACTORS TO SAFETY FACTORS

Dead-to-live load ratio	D/L	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
dead load factor	A	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
live load factor	B	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Limit state: rupture										
safety factor	Ω	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95
resistance factor	ϕ	0.82	0.80	0.79	0.77	0.76	0.75	0.74	0.74	0.73
All other member limit states										
safety factor	Ω	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
resistance factor	ϕ	0.97	0.95	0.93	0.91	0.90	0.89	0.88	0.87	0.86
Limit state: bolt, rivet failure										
safety factor	Ω	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34
resistance factor	ϕ	0.68	0.67	0.66	0.64	0.63	0.63	0.62	0.61	0.61
Limit state: screw failure										
safety factor	Ω	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
resistance factor	ϕ	0.53	0.52	0.51	0.50	0.50	0.49	0.48	0.48	0.47

The weld-affected zone in non-heat treatable alloys has the annealed (O) temper strength, and the weld-affected zone in heat-treatable alloys has a strength slightly less than the solution heat-treated (T4) temper. For this reason, buckling constants for weld-affected zones of all alloys are determined from Table B.4.1, which applies to O and T4 temper material.

B.5 Elements

B.5.1 Width of Flat Elements and Stiffeners

If the inside corner radius exceeds 4 times the element thickness, the inside radius is taken as 4 times the thickness in calculating the element width. This rule is arbitrary but deemed reasonable.

B.5.2 Radius of Curved Elements

The mid-thickness radius of curved elements is used to determine their slenderness to be consistent with the work by Clark and Rolf (1964).

B.5.3 Thickness of Elements

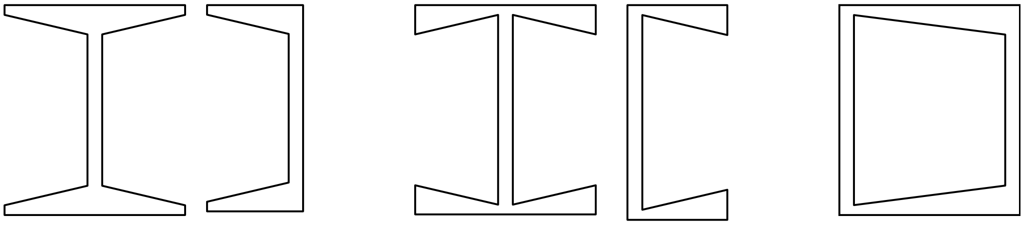
Kim (2003) provided the method used in this Section for determining the slenderness ratio for members that have linearly tapered thickness elements with $\delta \le 2.0$ (i.e., $t_{max} \le 3t_{min}$). The tapered flanges of American Standard channels and American Standard I beams meet this criterion.

Three types of edge supports for elements with tapered thickness are addressed in Section B.5.3:

a) Tapered thickness elements with the thick edge supported and the thin edge free (Figure CB.5.1(a)): For such elements, it is conservative to use b/t_{avg} for the slenderness ratio. Using b/t_{avg} gives a slenderness ratio that is conservative by as much as 28% compared to finite element analysis for $\delta = 2$. Section B.5.3a provides an approximate expression for the slenderness ratio that is less conservative and more accurate than using b/t_{avg}.

b) Tapered thickness elements with the thin edge supported and the thick edge free (Figure CB.5.1(b)): For such elements, the slenderness ratio can be approximated by $(1.02)\left(\frac{b}{t_{avg}}\right)$. Using b/t_{avg} understates the slenderness ratio by only 3% compared to finite element analysis, so this *Specification* allows the use of b/t_{avg}.

c) Tapered thickness elements supported on both edges (Figure CB.5.1(c)): The slenderness ratio can be approximated



(a) (b) (c)

Figure CB.5.1

by $(1.02+0.02\delta)\left(\frac{b}{t_{avg}}\right)$. Using b/t_{avg} understates the slenderness ratio by at most only 5% compared to finite element analysis, so this *Specification* allows the use of b/t_{avg}.

Once the slenderness ratio has been determined, use the *Specification* Section for a constant thickness element with the same edge conditions to determine the strength of the element.

B.5.4 Strength of Elements in Uniform Compression

The strength of elements in uniform compression is the weighted average of the strengths of the unwelded and weld-affected zones of the element. The strength of elements with transverse welds is not limited by yielding because yielding at a transverse weld does not cause an appreciable change in length. The weld-affected zone for transverse welds that extend across the full width of an element is the gross area of the element.

B.5.4.1 Flat Elements Supported On One Edge

Sooi and Peköz (1993) determined the post-buckling strength given in Section B.5.4.1 for slenderness ratios greater than S_2.

Using the buckling coefficient $k = 0.425$ for an element with one edge simply supported and the other free from Galambos (1998) Figure 4.2 and $\nu = 0.33$ (see Section A.3.1), the elastic buckling stress can be determined as

$$F_e = \frac{k\pi^2E}{12(1-\nu^2)(b/t)^2} = \frac{0.425\pi^2E}{12(1-0.33^2)(b/t)^2} = \frac{\pi^2E}{25.16(b/t)^2}$$

$$= \frac{\pi^2E}{(5.02b/t)^2}$$

In columns buckling about a principal axis that is not an axis of symmetry (for example, channels buckling about the weak axis), the centroid of the stresses may not be the same as that for the full section. This is due to the non-linear post-buckling stress distribution in the section's elements. Although some post-buckling strength may exist, it may not be as large as that if the buckling axis were an axis of symmetry. Therefore, this Section limits the strength in such cases to the elastic local buckling strength.

B.5.4.2 Flat Elements Supported on Both Edges

Using the buckling coefficient $k = 4.00$ for an element simply supported on both edges from Galambos (1998) Figure 4.2 and $\nu = 0.33$ (see Section A.3.1), the elastic buckling stress is:

$$F_e = \frac{k\pi^2E}{12(1-\nu^2)(b/t)^2} = \frac{4.00\pi^2E}{12(1-0.33^2)(b/t)^2} = \frac{\pi^2E}{2.673(b/t)^2}$$

$$= \frac{\pi^2E}{(1.64b/t)^2}$$

Jombock and Clark (1968) determined the post-buckling strength given in Section B.5.4.2 for slenderness ratios greater than S_2.

B.5.4.3 Flat Elements Supported on One Edge and with a Stiffener on the Other Edge

The study by Sooi and Peköz (1993) used to establish these provisions was based on sheet metal shapes where the thickness of the stiffener is the same as the thickness of the stiffened element, and these provisions give the same result regardless of the stiffener thickness. Therefore, this *Specification* requires that the stiffener be at least as thick as the element to be stiffened.

The denominator in each of Equations B.5-3 and B.5-4 for ρ_{ST} is the radius of gyration of a stiffener adequate to give the element being stiffened the strength of an element supported on both longitudinal edges (R_a). Sooi and Peköz adapted the equations for R_a from the AISI *Specification* (1986) and compared them with the equation proposed by Sharp (1966). The elastic buckling analysis by Sharp shows that $R_a = 6t$. Elastic buckling begins at a b/t ratio equal to S_e where S_e is the limiting b/t ratio at which a stiffened element is fully effective. At this value of b/t, the value of R_a obtained from Equation B.5-3 matches the value derived by Sharp. A linear relationship is assumed between R_a and b/t if b/t is between $S_e/3$ and S_e.

To develop post-bucking strength of the stiffened element, R_a is greater than $6t$. An edge stiffened element with a b/t ratio exceeding S_e has post-buckling strength. Equation B.5-4 addresses such cases, where b/t is between S_e and $2S_e$. There is insufficient test data to develop an equation for R_a when b/t exceeds $2S_e$.

The limitation on the D_s/b ratio prevents adverse interaction between local buckling of the edge stiffener and the stiffened element.

Stiffening bulbs and other complex shapes may provide greater strengths than those provided for in Section B.5.4.3. Sharp (1993) gives a method for estimating the buckling strength for these other shapes.

B.5.4.4 Flat Elements Supported on Both Edges and with an Intermediate Stiffener

The provisions in this Section are based on Sharp (1966), who developed an equation for flat elements supported on both edges with multiple intermediate stiffeners. Sooi and Peköz (1993) found that these provisions, in conjunction with the weighted average method, gave good agreement with test strengths.

B.5.4.5 Curved Elements Supported on Both Edges

In theory, the elastic buckling strength of an ideal cylindrical shell loaded in compression can be determined by substituting an equivalent slenderness ratio of $4.0\sqrt{\frac{R_b}{t}}$ into the column formula. The buckling strength of actual shells, however, is strongly affected by imperfections in the geometry and end conditions. Tests indicate that this effect tends to increase with increasing R_b/t. The effect of imperfections is taken into account by the formulas in this Section, which are conservative when compared with the results of numerous tests on tubes and cylinders (Clark and Rolf (1964), Weingarten, Morgan, and Seide (1965)). Section B.5.4.5 is based on elastic local buckling strength since severe deformations occur at this load.

B.5.4.6 Flat Elements Alternate Method

Strengths determined using the provisions of this Section agree well with the test strengths reported by Bijlaard and Fisher (1952) for I beams and square tubes.

Sections B.5.4.1 through B.5.4.5 address the compressive strengths of beam elements assuming that the supported edges of elements are fixed against translation and free to rotate.

Section B.5.4.6 provides an alternate method by which a more accurate assessment of element support conditions can be used to determine the compressive strength. The use of Section B.5.4.6 for welded members is prohibited because the accuracy of the alternate method given in Section B.5.4.6 has not been established for welded members.

To determine F_e, the elastic buckling stress of the column with continuous lateral support, a linear elastic analysis such as the finite strip method, by which a member is divided into strips that run the length of the member, may be used.

B.5.5 Strength of Elements in Flexure

The local buckling strength of elements in flexure is not affected by welds in the tension zone of the element. Therefore, only weld-affected zones in the compression portion of the element are considered in determining the local buckling strength of these elements. Further study is required to account for the effect of the location of the weld-affected zone, which is not addressed by the *Specification.*

B.5.5.1 Flat Elements Supported on Both Edges

The coefficients in the formula for inelastic buckling strength are assumed to be the same as for solid rectangular shapes (Section F.4). When the neutral axis is at the mid-height of the element, the equivalent slenderness ratio is $0.65b/t$, which applies to an element in bending with both edges simply supported. Simple support is assumed because the boundary conditions at the compression edge are more important than those at the tension edge and compression elements supporting the compression flange may buckle at the same time as the web.

B.5.5.2 Flat Elements Supported on Tension Edge, Compression Edge Free

The coefficients in the formula for inelastic buckling strength were assumed to be the same as for solid rectangular shapes (Section F.4). The equivalent slenderness ratio of $3.5b/t$ is based on partial restraint against rotation at the supported edge.

Section B.5.5.2 is based on elastic buckling strength. This type of element is assumed to have negligible post-buckling strength.

B.5.5.3 Flat Elements Supported on Both Edges and with a Longitudinal Stiffener

The coefficients in the formula for inelastic buckling strength are assumed to be the same as for solid rectangular shapes (Section F.4). The equivalent slenderness ratio is $0.29b/t$ based on simple support at the edges and at the stiffener using theory from Bleich (1952).

Section B.5.5.3 requires that a longitudinal stiffener on a beam web shall be located so that the distance from the toe of the compression flange to the stiffener's centroid is 0.4 times the distance from the toe of the compression flange to the beam's neutral axis. This is the optimum location for increasing the buckling strength of the web. The resulting strength of the web is based on Bleich (1952). The stiffener's required moment of inertia is the same as that used in earlier ASCE specifications (1962a, 1962b), and agrees with tests by Rockey (1958). The factor α accounts for the effect of eccentricity for a stiffener on one side of the web only (Massonnet (1962)).

B.5.5.4 Flat Elements Alternate Method

Sections B.5.4 and B.5.5 address the compressive strengths of beam elements assuming that the supported edges of elements are fixed against translation and free to rotate. Section B.5.5.4 provides an alternate method by which a more accurate assessment of element support conditions can be used to determine the compressive strength. Kim (2003) showed that Section B.5.5.4 is also reasonably accurate for shapes not addressed by Sections B.5.4 and B.5.5 and composed entirely of flat elements, including those with single or multiple intermediate stiffeners. The use of Section B.5.5.4 for welded members is prohibited because the accuracy of the alternate method given in Section B.5.5.4 has not been established for welded members.

When Section F.8.2.3 is used in combination with the weighted average strength method given in Section F.8.3, the strength of a stiffened element need not be limited to the strength of the stiffener since the elastic buckling strength determined is the strength of the entire section, accounting for all elements.

To determine F_e, the elastic buckling strength of the beam with continuous lateral support, a linear elastic analysis such as the finite strip method, by which a member is divided into strips that run the length of the member, may be used.

B.5.6 Elastic Buckling Stress of Elements

The elastic buckling stress of elements is the elastic local buckling stress. Since elastic local buckling stresses are used for the design of both members for compression (Chapter E) and members for flexure (Chapter F), the table of elastic local buckling stresses is provided in Chapter B.

The elastic local buckling stress F_e for elements supported on one edge and with a stiffener on the other edge is based on the effectiveness of the stiffener. When the stiffener has no effectiveness, $\rho_{ST} = 0$ and $F_e = \frac{\pi^2 E}{(5.0b/t)^2}$ and when the stiffener is fully effective, $\rho_{ST} = 1$ and $F_e = \frac{\pi^2 E}{(1.6b/t)^2}$

The elastic buckling stress of elements in uniform compression is used to check the interaction between member buckling and local buckling for columns (Section E.5), and the interaction of lateral-torsional buckling and flange buckling for single web beams (Section F.2.3). This interaction can only govern if postbuckling strength is used. Postbuckling strength is used in Sections B.5.4.1, B.5.4.2, and B.5.4.3.

B.6 Fabrication and Erection

Section B.6 invokes Chapter M for fabrication and erection issues.

B.7 Evaluation of Existing Structures

Section B.7 invokes Appendix 5 for the evaluation of existing structures.

Chapter C Design for Stability

C.1 General Stability Requirements

Design for stability includes the analysis to determine required strengths as well as proportioning the members and connections so they have adequate available strength.

C.2 Calculation of Required Strengths

The five factors listed in Section C.2 are the factors that must be accounted for in an accurate stability analysis of a structure.

1) The designer must determine whether connection deformations are significant and need to be considered.
2) Second-order effects are included in many structural analysis programs. To determine if a program properly includes second-order effects, the program's results can be compared to the two benchmark problems given in the AISC 2005 Specification commentary to Section 7.3. Most structural analysis programs that purport to address second-order effects include P-Δ effects, but some do not include P-δ effects. P-δ effects must be included in determining the required strength of individual compression members.
3) The pattern of geometric imperfections should be similar to the anticipated buckled shape of the structure and to the displacements caused by loads. Since the *Specification for Aluminum Structures* does not establish erection tolerances, Section C.2 requires that the imperfections be the tolerances specified by the designer. For example, if the maximum out-of-plumbness requirement for the structure is specified as $H/500$, then the imperfection at the top of a column relative to its base is $H/500$ where H is the height of the column.

   Geometric imperfections could also be accounted for by applying equivalent notional loads to the structure that are a fraction of the gravity loads for nominally vertical and horizontal members. However, including the geometric imperfections in the analysis model is applicable to all structural configurations.
4) The factor for flexural stiffness τ_b due to inelasticity matches the factor used by AISC and ranges from 1.0 for $P_r \le 0.5P_y$ to 0 for $P_r = P_y$. This can be addressed by using $\tau_b I$ in place of I in the analysis.
5) The 0.8 factor on member stiffness due to uncertainty in stiffness and strength is the product of the resistance factor for columns (0.90) and the reduction factor (0.85) on the buckling strength of slender columns. The 0.8 factor also accounts for additional softening under combined axial compression and bending of intermediate or stocky columns. This can be addressed by using $0.8E$ in place of E in the analysis.

The effective length method is not included in Chapter C since a second-order analysis must be made to determine if the effective length method is appropriate, and the method in Section C.2 is more direct. Also, it is often quite difficult to properly determine effective lengths. However, since Section C.1 allows any elastic method, the effective length method can be used if properly applied.

The reason for factoring ASD loads by 1.6 is that the structure may not behave linearly, which is why 2nd order analysis is performed. To produce the same overall result with ASD and LRFD, the ASD analysis must be done at the LRFD load level. Then, since ASD results are compared to ASD allowable stresses, the ASD results must be divided by 1.6.

C.3 Calculation of Available Strengths

Bracing requirements given in Appendix 6 do not apply to bracing that is included in the structural analysis performed in accordance with Section C.2.

Chapter D Design of Members for Tension

D.1 General Provisions

The allowable tensile strength for building structures is the lesser of the two values that result from applying a safety factor of 1.65 to the yield strength of the gross section and 1.95 to the ultimate strength of the net section. The corresponding safety factors for bridge structures are 1.85 and 2.2. These factors match those in ASCE (1962a) and ASCE (1962b) and have been used in the *Specification for Aluminum Structures* since its first edition in 1967.

D.2 Tensile Strength

The axial tensile strength is the lesser of 1) the yield strength of the gross section and 2) the ultimate (fracture) strength of the net section. This is because the net section usually exists over only a short portion of the overall length of the member, and the elongation of the member resulting from yielding across the net section is small. Thus, yielding on the net section is not a limit state.

The strength of tension members with transverse welds is limited by the strength of the transverse weld. Transverse welds are welds with an axis perpendicular to the member axis. If the entire cross section of the member is weld-affected, the tensile strength is $F_{tuw} A_e$. Yielding at a transverse weld is not a limit state, because, in a similar manner as for yielding at the net section, the elongation of the member resulting from yielding across a transverse weld is small.

Longitudinal welds are welds with an axis parallel to the member axis. Usually only part of the cross section of longitudinally welded members is weld affected. The strength of a cross section with only part of its area weld affected can be estimated by adding up the strength of the material in the weld-affected zone and the unaffected material outside this zone (Hill, et al. (1962)). Hill and Brungraber (1962) showed that for members with part of the section weld-affected, the strength is the sum of the strength of the weld-affected material and the strength of the non-weld-affected material.

D.3 Area Determination

D.3.1 Net Area

Figures CD.3.1 and CD.3.2 illustrate the notation of this Section. The net section area for the bar shown in Figure CD.3.1 is

$$A_{net} = \left(b - 2d + \frac{s^2}{4g}\right) t$$

where t is the thickness of the bar and d is the diameter of the hole. In Figure CD.3.2, the angle section is flattened out into a bar for the purpose of calculating the net section. The flattened width is $a + b - t$.

For staggered holes in shapes with different thickness elements (for example, staggered holes in a channel flange and web), the *Specification* does not address the thickness to be used to determine the net area from the net width based on the $s^2/4g$ rule. A possible approach in this instance is to use the weighted average thickness (weighted by the length of the failure path in a given element) (see Gaylord et al. (1992)).

The effective width of punched holes is the hole diameter + 1/32 in. to account for break-out on the back side of the part that punching may cause.

D.3.2 Effective Net Area

May and Menzemer (2005) showed that the effective area in tension is less than the net area due to the non-uniform stress distribution across the section at the connection for angles, tees, and channels connected by some but not all of their elements. This is accounted for by using the net effective area to calculate the tensile stress in the section. Designers should not combine bending stress due to the connection eccentricity with axial stress on the net effective area since the effect of the eccentricity is accounted for in the net effective area determination.

To determine the eccentricities:

a) For tees connected only by their flanges (Figure CD.3.3(a)), the eccentricity in the y direction is the distance from the outside face of the flange to the neutral axis of the tee parallel to the flange. The eccentricity in the x direction is zero. For I beams connected only by their flanges (Figure CD.3.3(b)), split the section at the neutral axis parallel to the flanges to create two tees.

b) For channels connected only by their webs the eccentricities are as shown in Figure CD.3.4.

c) For angles connected only by one leg, the eccentricity in one direction is the distance from the face of the connected leg to the neutral axis of the angle parallel to the connected leg (Figure CD.3.5(a)). The eccentricity in the other direction is determined from a section obtained by subtracting the portion of the connected leg outside the centerline of the fastener closest to the unconnected leg. The eccentricity is the distance perpendicular to the unconnected leg from the centerline of the fastener closest to the unconnected leg to the neutral axis of the remaining section (Figure CD.3.5(b)).

d) For I beams connected only by the web, eccentricities are determined as shown in Figure CD.3.6.

If there is only one row of bolts in the direction of load or the only weld has an axis perpendicular to the direction of load, the length of the connection L is zero and the net effective area is the net area of the connected elements.

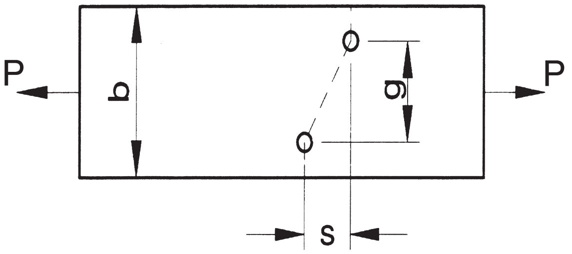


Figure CD.3.1
BAR IN TENSION

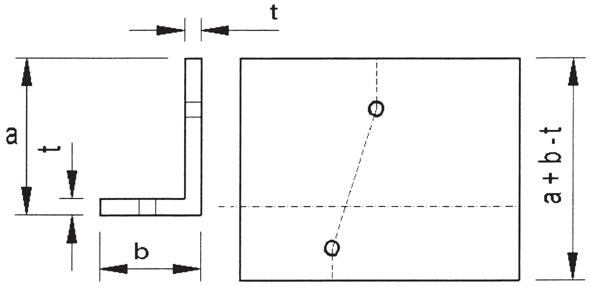
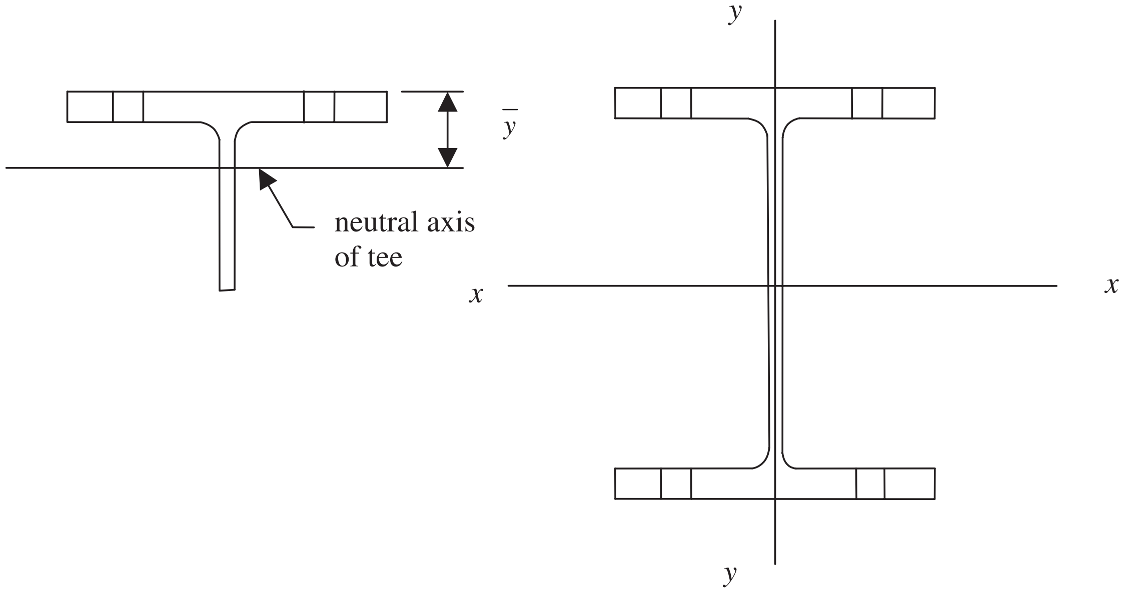


Figure CD.3.2
ANGLE IN TENSION



(a) (b)

Figure CD.3.3

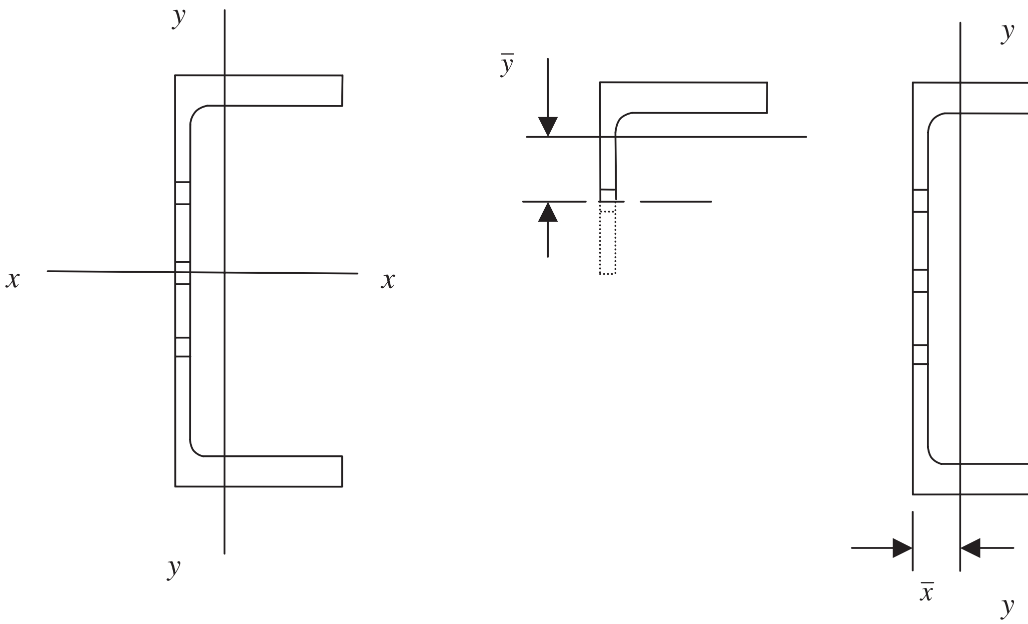
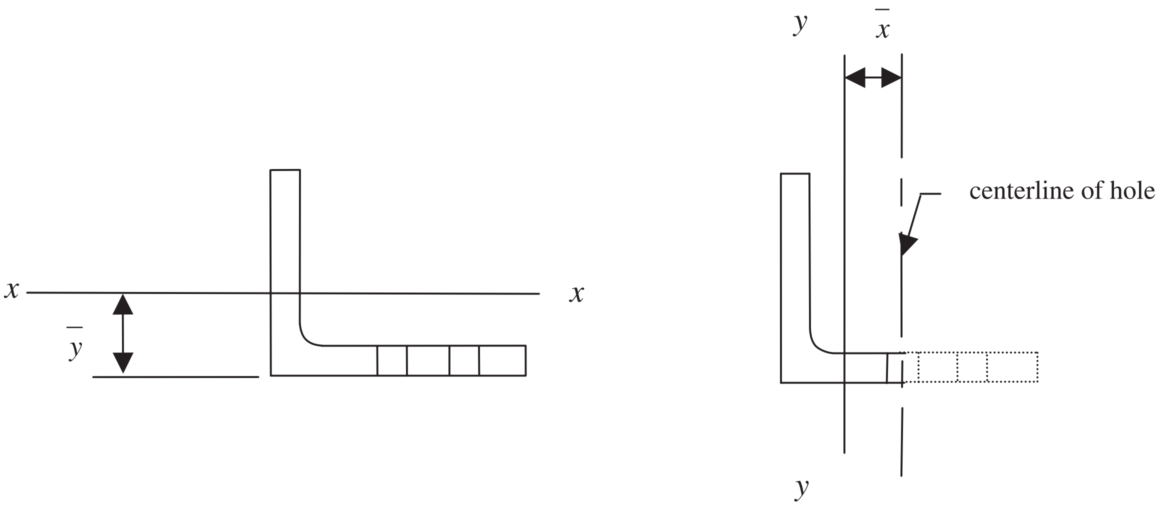


Figure CD.3.4



(a) (b)

Figure CD.3.5

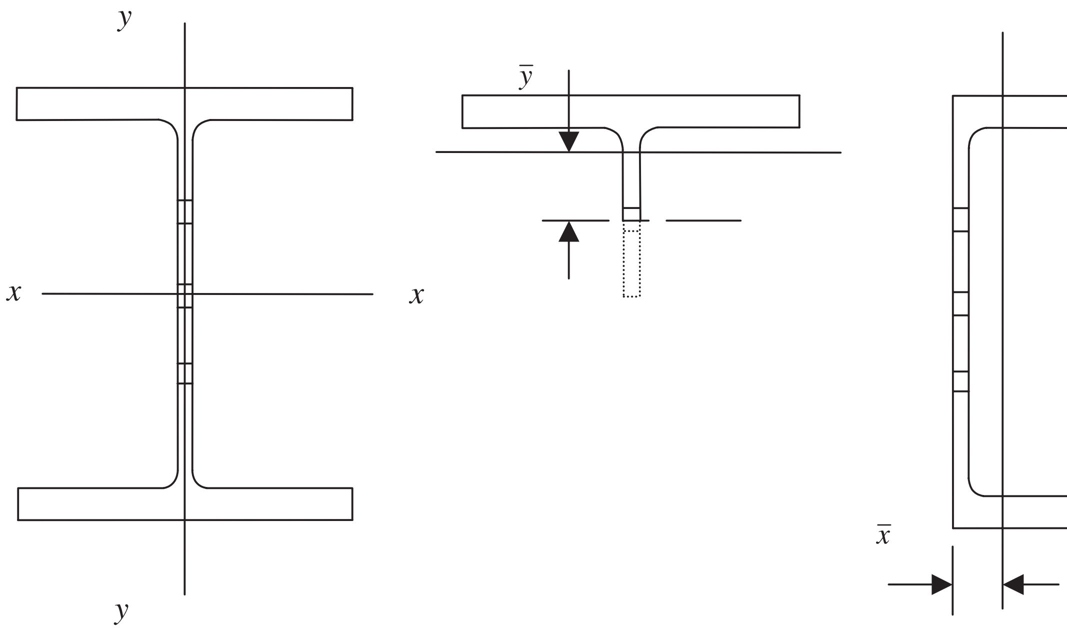


Figure CD.3.6

Chapter E Design of Members for Compression

E.1 General Provisions

Because column member buckling strength (E.3) does not account for an approximate 0.85 factor on strength due to standard tolerance on out-of-straightness, the safety factor for column member buckling for members designed using this *Specification* prior to 2010 was actually about (0.85)(1.95) = 1.66. Because the 2010 *Specification* includes the 0.85 factor in the column member buckling strength but the safety factor has changed from 1.95 to 1.65, column member buckling allowable strengths did not change in the 2010 *Specification.*

In the 2010 *Specification,* the safety factor for column local buckling strength changed from 1.95 to 1.65 to make it consistent with the safety factor for local buckling of beams. Unlike member buckling, local buckling strengths need not be reduced for out-of-straightness since Sharp (1993) notes that "the practical plate with initial crookedness . . . has essentially the same strength as that for the perfectly flat plate."

E.2 Effective Length

Chapuis and Galambos (1982) addressed the effective length of aluminum columns as a factor k times the length of the column between lateral supports.

E.3 Member Buckling

The inelastic buckling formulas in this Section use the tangent modulus column formula:

$$F = \frac{\pi^2 E_t}{(kL/r)^2}$$

where:

F = column buckling stress
E_t = tangent modulus (slope of stress strain curve) corresponding to F_e
kL = effective length of column
r = least radius of gyration of column.

In the elastic range, this formula is simply the Euler column formula, which gives the buckling strength for values of kL/r exceeding S_2. For values of kL/r less than S_2, Templin, et al. (1938) and Clark and Rolf (1966) showed that the tangent modulus formula is approximated closely by a straight line.

Hill and Clark (1956) and Batterman and Johnson (1967) showed that load eccentricity and initial crookedness reduce the buckling strength. The 0.85 factor on inelastic and elastic member buckling accounts for these effects. Sharp (1993) showed that strength of a 6061-T6 column that is out-of-straight by standard mill tolerance is about 83% of the strength of a perfectly straight column. AISC (2005) addresses out-of-straightness in steel column member buckling with a 0.877 factor on buckling strength, and uses a safety factor of 1.67 for column buckling.

For very short columns, the compressive strength is the compressive yield strength. Such columns are sometimes referred to as stub columns, for which the limit state is yielding rather than buckling. This is addressed in Section B.5.4, where the local buckling strength is limited by the yield strength.

E.3.1 Flexural Buckling

For flexural buckling, the slenderness ratio kL/r is the greater of the slenderness ratios taken about each of the principal axes of the member.

E.3.2 Torsional and Flexural-Torsional Buckling

Section E.3.2 is similar to the AISC (2005) Section E4 for torsional and flexural-torsional buckling. Based on data provided by Abramson (1977), Sharp (1993) showed that the member buckling strength equations of Section E.3 can be used for torsional-flexural buckling if an equivalent slenderness ratio is defined. The equivalent slenderness ratio $(kL/r)_e$ is based on the elastic torsional-flexural buckling stress.

For point-symmetric sections such as cruciforms, torsional buckling is the most likely mode of failure and F_e becomes equal to F_{et}.

E.4 Local Buckling

The strength of elements with welds that are not along the element edges may have less strength than elements without welds for two reasons:

1) Welding reduces the yield and ultimate strength of the metal. This can be accounted for by using the welded yield strength and welded buckling constants to determine the element strength.
2) Welding may introduce distortions. AWS D1.2 Section 4.15.4 requires a flatness tolerance on welded webs of $d/100$, where d = web depth, and Section 4.15.5 requires a flatness tolerance of $w/100 < 0.25$ in. on welded flanges, where w = full width of the flange. For extrusions, *Aluminum Standards and Data 2009* Table 11.8 requires a flatness tolerance of 0.4% to 1.4% of the width, depending on part thickness and width, being greater for thin parts and large widths. For sheet and plate, *Aluminum Standards and Data 2009* Table 7.17 requires a flatness tolerance of 0.5% to 1.3% of the width. Since the flatness tolerances for unwelded mill products and welded parts are approximately the same, distortions are not greater in welded elements than unwelded elements, and their strengths should not differ because of distortions.

Sharp (1993) Figure 7.9 shows that the compressive strength of longitudinally edge-welded elements is slightly less than the unwelded strength, and considerably greater than the all-welded strength. The flatness tolerance for the test specimens ranged from 0.1% to 0.7% of the width. Sharp noted that "Welds decreased the strength compared to unwelded plates but the decrease was not as much as that calculated for all-welded material". Compressive tests on welded aluminum plates (Conley, et al. (1963)) have demonstrated that the welds have little effect on postbuckling strength. To account for the reduction in strength in the weld-affected zone, a weighted average method is used.

E.4.1 Weighted Average Local Buckling Strength

Crocket (1942) showed that the local buckling strength of a member is the sum of the local buckling strength of the member's elements. The compressive strength of portions of a column at the intersection of elements (for example, at the web-flange juncture in a channel) is taken as F_{cy} since this material does not buckle locally and is not included in the area of the flange element or the web element.

E.4.2 Alternate Local Buckling Strength

The alternate method for determining the local buckling stress is described in Section B.5.4.6.

E.5 Interaction Between Member Buckling and Local Buckling

Sections B.5.4.1 and B.5.4.2 take advantage of the post-buckling strength of certain types of elements, because such elements may buckle elastically without causing failure of the member. However, if the local buckling stress of the section is less than the member buckling strength of the column, the reduced stiffness that accompanies local buckling may reduce the member buckling strength. Sharp (1970) developed the strength equation given in Section E.5 to address this interaction between member buckling and local buckling. Sharp's equation agrees well with the results of compression tests on H-section and box section columns with thin elements reported by Bijlaard and Fisher (1952).

The interaction between member buckling and local buckling is more likely to govern the strength when member buckling is elastic and an element of the member has a high slenderness ratio.

The elastic local buckling strengths given in Table B.5.1 are accurate for square tube shapes and conservative for other shapes. These values can be quite conservative for sections with elements whose edge restraint is more rigid than an element that is simply supported. Section E.4.2 provides a more accurate and less conservative method to determine the strength in such cases.

E.6 Welded Compression Members

Brungraber and Clark (1962) investigated the strength of welded aluminum compression members. Welding can affect a member's compression strength by reducing strength in the heat-affected zone, causing residual stresses, and distorting the member shape. The effect of welding on element strength is addressed in Section E.4.

E.6.1 Compression Members with Transverse Welds

Transverse welds not at the ends of a column supported on both ends or in a cantilever column may appreciably decrease the member buckling strength. Sharp (1993) showed that for these cases the strength calculated as though the entire column were of welded material is conservative.

If a column has both longitudinal and transverse welds, the strength determined considering the transverse welds usually is less than the strength determined considering the longitudinal welds.

For circumferentially welded cylinders with $R_b/t > 20$, Sharp (1993) showed that Section B.5.4.5 may be very unconservative. Apparently the circumferential welds can cause more severe geometric imperfections in the thin-walled cylinder than those in relatively heavy-wall cylinders. More research is needed to establish accurate design rules for circumferentially welded, thin-walled cylinders.

E.6.2 Compression Members with Longitudinal Welds

The strength of a cross section with only part of its area heat affected can be estimated by adding up the strength of the material in the heat-affected zone and the unaffected material outside this zone (Hill, et al. (1962)).

Sharp (1993) showed that for calculating the member buckling strength, the buckling formula constants given in Table B.4.1 (non-artificially aged tempers) best represent weld-affected material.

Chapter F Design of Members for Flexure

F.1 General Provisions

Resistance and safety factors are discussed in Sections B.3.2.1 and B.3.2.2.

F.1.1 Bending Coefficient C_b

The bending coefficient is applied to segments of beams between brace points. Inflection points are not brace points.

The lateral-torsional buckling strengths given in Sections F.2.1, F.3, F.4.2, and F.5 are based on a uniform moment over the unbraced length. If the moment varies over the unbraced length, the lateral-torsional buckling strength is greater than the strength given by Sections F.2.1, F.3, F.4.2, and F.5. This strength increase can be accounted for by using the bending coefficient C_b given in F.1.1 provided by Kirby and Nethercot (1979).

F.1.1.1 Doubly Symmetric Shapes

The formula for the bending coefficient is the same as used in the 2010 AISC Specification and given in the SSRC Guide 6th edition.

If the free end of a cantilever is torsionally braced, equation F.1-1 can be used to compute C_b. The SSRC Guide 6th edition Section 5.2.9 provides additional information on cantilevers.

F.1.1.2 Singly Symmetric Shapes

Application of the C_b factor to singly symmetric sections in the same manner as for doubly symmetric sections has been shown to be unconservative in certain cases by Kitipornchai (1986). The unconservative cases arise if the C_b factor is applied to the critical moment determined for the case of larger flange in compression, M_L, when it is possible that somewhere in the unbraced segment the smaller flange may be in compression. In such cases, the member must also be checked at the location where the smaller flange is subjected to its maximum compression.

Kitipornchai (1986) showed that if one of the two flanges is small such that $I_{cy}/I_y \leq 0.1$ or $I_{cy}/I_y \geq 0.9$, C_b should be taken as 1.0. C_b is also to be taken as 1.0 if rotational restraint is considered ($k_y < 1$) since Equation F.1-1 overestimates C_b when the unbraced length is factored by a k_y less than 1.

For continuous beams there are no directly derived values of C_1 and C_2. For this reason rational analysis must be used in estimating the values of these coefficients for such applications. It can be shown that for loading as shown in Figure CF.1.1, reasonably conservative results are obtained by taking:

$C_1 = 0.41C_b$ and $C_2 = 0.47C_b$ when the smaller (top) flange is in compression (shown in the top two cases of Figure CF.1.1) and

$C_1 = 0$ and $C_2 = 0$ when the larger (top) flange is in compression (shown in the bottom two cases of Figure CF.1.1).

F.2 Open Shapes

F.2.1 Lateral-Torsional Buckling

In the inelastic stress range the lateral-torsional buckling strength equation employs the straight line approximation to the tangent modulus buckling curve that is also used for columns. Tests have shown this curve to be conservative for beams (Clark and Rolf (1966)). S_1 isn't needed for lateral-torsional buckling because yielding is addressed in Section F.8.

Clark and Hill (1960) determined the lateral-torsional buckling strength of single web beams about their strong axis. A simple span beam restrained against movement laterally and vertically at the supports, but free to rotate about the vertical and horizontal axes at the ends is assumed. A symmetrical section and uniform moment are also assumed. The expressions Clark and Hill derived for lateral-torsional buckling were complicated, so a simplified approximate method for estimating strength was developed. An effective slenderness ratio $L/1.2r_y$ was found to be conservative for standard aluminum shapes.

Section F.2.2 allows the designer to calculate a more accurate value for r_y. The formulas of Section F.2.1 are based on an approximation in which the term L_b/r_y replaces a more complicated expression involving several properties of the cross section. Because of this approximation, Section F.2.1 gives very conservative results for certain conditions, namely for values of L_b/r_y exceeding about 50 and for beams with transverse loads applied in a direction away from the beam's shear center. To compute more accurate bending strengths for these cases, the value of r_y in Section F.2.1 may be replaced by the effective radius of gyration r_{ye} given in Section F.2.2.

Figure CF.2.1 compares the slenderness ratios of 17 American Standard I-beams using r_y and using r_{ye}. Using r_y is very conservative for moderate and high slenderness ratios and for all of the sections, in many cases by a factor of two or more. Sharp's (1993) comparison of test data and calculations using r_{ye} shows that using r_{ye} is conservative.

For singly-symmetric sections unsymmetric about the bending axis Section F.2.2.2 or F.2.2.3 may be used. The latter is more accurate.

Winter (1941) showed a method for taking advantage of the effect of bracing the tension flange. He derived the elastic critical moment M_e for pure bending for a singly symmetric I-section with the tension flange prevented from lateral displacement but free to rotate:

$$M_e = \frac{EI_c d\pi^2}{L_b^2} + \frac{GJ}{d} \qquad \text{(CF.2-1)}$$

r_{ye} can be evaluated for this case using this M_e in Equation F.2-3. In equation CF.2-1 I_c is the moment of inertia of the compression flange about the web.

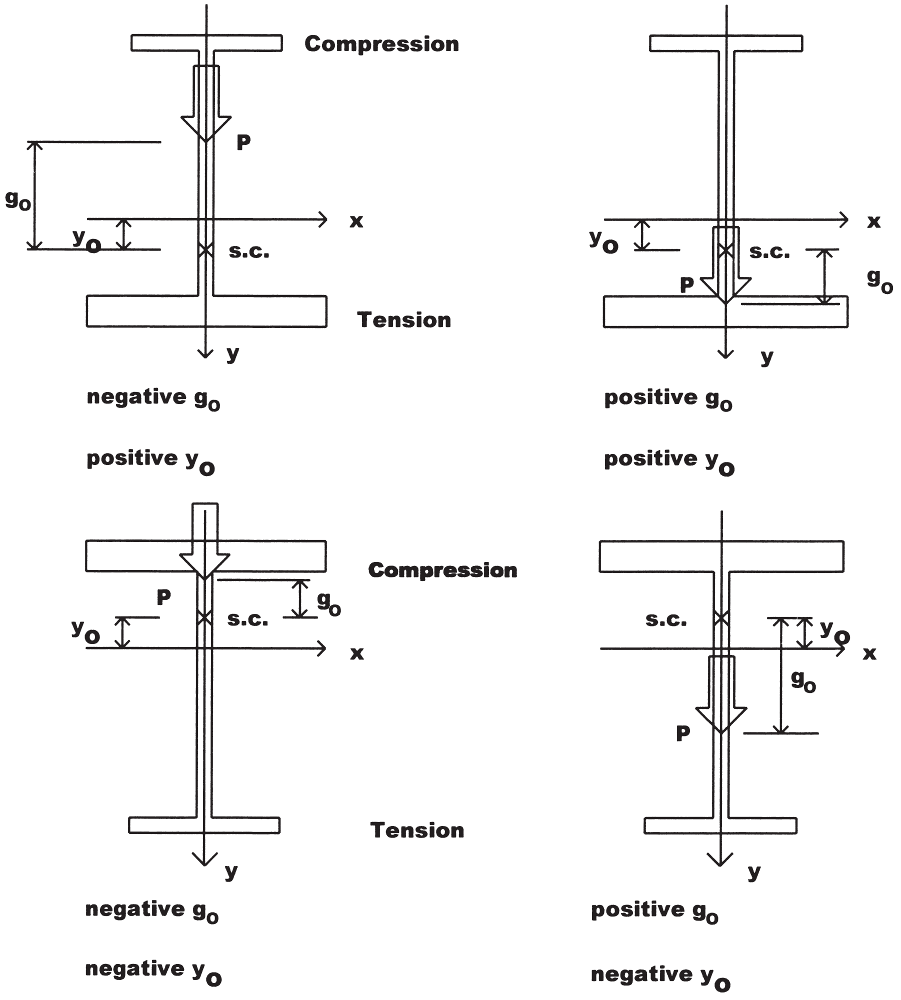


Figure CF.1.1
ORIENTATION OF THE AXES AND CROSS-SECTIONAL NOTATION

F.2.2 Effective Radius of Gyration r_{ye}

F.2.2.1 Shapes Symmetric About the Bending Axis

Bending strengths are determined at the brace points of beams as well as between brace points. At brace points of doubly symmetric beams use Equation F.2-1 to calculate the allowable stress. Use the same equation between brace points if the beam is subjected to lateral loads that are applied only at the shear center of the section. Use Equation F.2-2 to calculate the allowable stress between brace points when a transverse load is applied to the top or bottom flange of the beam and the load is free to move laterally with the beam if it should buckle.

Selection of the proper equation for r_{ye} is illustrated by Figure CF.2.2. At point B for both beams, use Equation F.2-1. Use the same equation for point A if the distributed load is applied at the level of the neutral axis. If the distributed load is not applied at the level of the neutral axis, use Equation F.2-2. The approach for checking the moment at point C is discussed in connection with the selection of C_b in Section F.2.2.3.

F.2.2.2 Singly Symmetric Shapes Unsymmetric About the Bending Axis

For singly symmetric shapes that are unsymmetrical about the bending axis, approximate bending strength can be determined using Section F.2.2.1 to determine r_{ye} taking r_y, I_y, S_c and J as though both flanges were the same as the compression flange with the overall depth remaining the same. This approximation is quite conservative when the smaller flange is in compression. The approximation may be unconservative when the larger flange is in compression.

F.2.2.3 Shapes Unsymmetric About the Bending Axis

Section F.2.2.3 applies to shapes symmetric about the bending axis as well as shapes unsymmetric about the bending axis. However, Section F.2.2.1 gives the same results as

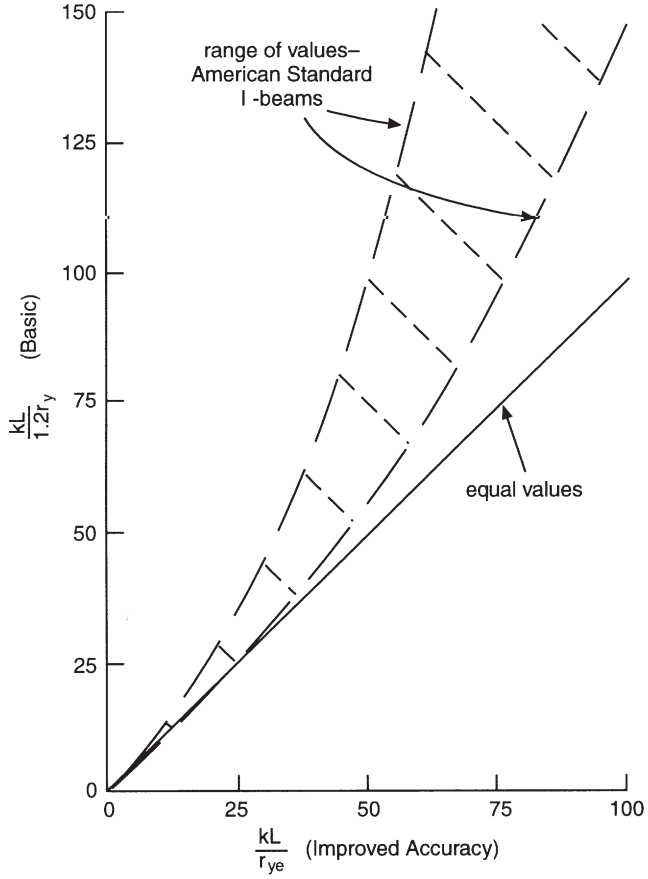


Figure CF.2.1
EQUIVALENT SLENDERNESS RATIOS FOR LATERAL BUCKLING

F.2.2.3 for shapes symmetric about the bending axis and is easier to apply. Therefore, to guide users to the most efficient way to use this *Specification,* the title for F.2.2.3 is "shapes unsymmetric about the bending axis".

Section F.2.2.3 applies to any beam bent about the strong axis by moments or by lateral loads applied through the shear center of the section. Equation F.2-4 was derived by Clark and Hill (1960) based on elastic torsional-flexural buckling theory. This expression considers non-symmetry of the section about the bending axis as well as the location of the laterally applied load with respect to the shear center.

The orientation of the axes and the cross-sectional notation are illustrated in Figure CF.1.1. The magnitudes of y_o, torsion constant J and the warping constant C_w can be determined from references such as Roark and Young (1989). The approximate formula for j given in Equation F.2-8 is based on work by Kitipornchai et al. (1986).

F.2.3 Interaction Between Local Buckling and Lateral-Torsional Buckling

This Section accounts for the effect that the reduced stiffness due to local buckling may have on the lateral buckling strength of single web beams based on work by Sharp (1970). The nominal strength expression was rearranged from the expression given in the 2005 *Aluminum Design Manual* but gives the same strength.

F.3 Closed Shapes

This section applies to closed shapes, defined in the glossary as hollow shapes that resist lateral-torsional buckling primarily by torsional resistance rather than warping

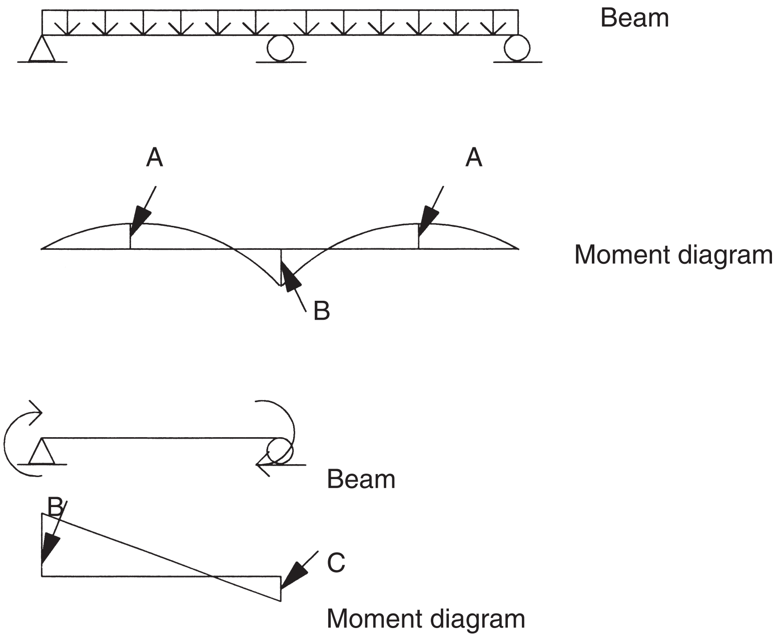


Figure CF.2.2
BEAM AND MOMENT DIAGRAM EXAMPLES

resistance. The wall thickness need not be uniform.

The slenderness ratio of a closed shape used in Section F.3 is $1.6\sqrt{\frac{2L_bS_c}{\sqrt{I_yJ}}}$ It was derived using the more general theoretical equation for lateral buckling strength and ignoring the term that represents the warping resistance of the beam, since, for closed shapes, this term is usually small in comparison to the term that represents St. Venant torsion. The two terms are equal when $C_w = 0.038JL_b^2$. If C_w is not small compared to $0.038JL_b^2$, Section F.2 gives more accurate results.

F.4 Rectangular Bars

F.4.1 Yielding and Rupture

Clark and Rolf (1966) showed that rectangular bars can undergo bending moments that are considerably greater than those predicted on the basis of the ordinary flexure formula and determined a shape factor for yielding of 1.30. Sharp (1993) determined shape factors for yielding of 1.32 and rupture of 1.46 for 6061-T6. This *Specification* uses 1.30 and 1.42, respectively.

F.4.2 Lateral-Torsional Buckling

If a rectangular bar is laterally unsupported and is sufficiently narrow in cross section, it can fail by lateral-torsional buckling. Section F.4.2 accounts for this limit state, using $2.3(d/t)\sqrt{L_b/d}$ as the slenderness ratio. In the intermediate slenderness ratio range, the buckling strength is considerably affected by a redistribution of stress that accompanies plastic yielding, so that the apparent stresses at buckling are appreciably higher than values for single web beams. Clark and Rolf (1966) showed that the formula for buckling strength agrees well with the results of tests on rectangular bars.

The formulas are based on a uniform moment on a single span beam that is simply supported with the ends prevented from lateral deflection but free to rotate about the vertical axis.

F.5 Single Angles

The strength of single angles in flexure in this Section is similar to the AISC *Load and Resistance Factor Design Specification for Single-Angle Members,* 2000.

One difference from the AISC *Specification for Single-Angle Members* is that the yield strength is limited to $1.3M_y$ rather than $1.5M_y$. This is done to be consistent with Sections F.8.1.2 and F.8.2.2.

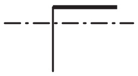
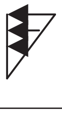
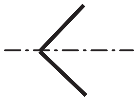
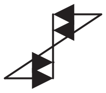
The local buckling strength of an angle leg depends on the degree of end fixity that the other leg provides and the variation in stress across the width of the angle leg. The lower bound on end fixity is a pinned support and the upper bound is a fixed support. Equivalent slenderness ratios (from Sharp (1993) Table 7.1) are summarized in Table CF.5.1 for an angle leg of width b and thickness t.

Case 1, uniform compression in an angle leg, is addressed in Section F.5a(2). Cases 2, 3, and 4 are addressed in Section F.5a(1) by conservatively using the worst case (Case 2) and assuming that the support is restrained slightly more than the pinned condition so that a factor of 4 (vs. 4.45) can be used.

F.5.1 Bending About Geometric Axes

Bending about geometric axes occurs when the moment is applied about an axis parallel to a leg of the angle as shown in Figure F.5.4. In such cases, when an angle is lat-

Table CF.5.1
EQUIVALENT SLENDERNESS RATIOS FOR ANGLE LEGS

Case		Stress distribution on leg of angle	Equivalent slenderness ratio/(*b*/*t*) (pinned support)	Equivalent slenderness ratio/(*b*/*t*) (fixed support)	Angle orientation
1	free edge		5.13	2.89	
	supported edge				
2	free edge		4.45	2.62	
	supported edge				
3	free edge		3.64	2.27	
	supported edge				
4	free edge		2.56	1.36	
	supported edge				

erally restrained at the point under consideration, the neutral axis is the geometric axis as shown on the left side of Figure F.5.4 and addressed in subsections a and b. When the angle is laterally unrestrained, the section will deflect laterally as well as normal to the bending axis, causing the neutral axis to incline as shown on the right side of Figure F.5.4 and addressed in subsection c.

F.5.2 Bending About Principal Axes

Formulas for determining β_w are given in Part V. Since these formulas are cumbersome, β_w values for some common angle sizes are given in Table CF.5.2. β_w varies only slightly with angle thickness for the angles listed in ADM Part V.

Table CF.5.2

Angle Size (in.)	β_w (in.)
8 × 6	3.31
8 × 4	5.48
7 × 4	4.37
6 × 4	3.14
6 × 3.5	3.69
5 × 3.5	2.40
5 × 3	2.99
4 × 3.5	0.87
4 × 3	1.65
3.5 × 3	0.87
3.5 × 2.5	1.62
3 × 2.5	0.86
3 × 2	1.56
2.5 × 2	0.85
equal legs	0.00

β_w is positive or negative depending on the direction of bending.

F.6 Pipes and Round Tubes

F.6.1 Yielding and Rupture

Clark and Rolf (1964) demonstrated that yielding of round hollow beams does not occur until the bending moment considerably exceeds the yield moment predicted by the ordinary flexure formula. This results from the non-linear distribution of stress in the inelastic range. Yielding does not become apparent as soon as the calculated stress in the extreme fiber reaches the yield strength because the less highly stressed fibers near the center of the beam are still in the elastic range.

The constants 1.17 and 1.24 used in the yielding and rupture strengths can be considered as shape factors for yielding and ultimate strength, respectively. The factor on yield was picked from curves of yield strengths at 0.2 percent offset for tubes with proportions similar to those listed in ADM Part V. The shape factor on ultimate strength was deduced from apparent and actual stress-strain curves at a stress corresponding to tensile rupture strength of the material.

F.6.2 Local Buckling

The inelastic buckling strength of round tubes in bending is based on experimental work by Clark and Rolf (1964).

S_2 is the slenderness R_b/t at which the bending buckling strength and axial compression buckling strength curves intersect. For values of R_b/t greater than S_2, the bending buckling strength is conservatively assumed to be the same as the axial compression buckling strength. This is shown in Figure CF.6.1 for 6061-T6.

The lower set of lines, two straight lines and a curved line, applies to both tubes and curved elements under uniform compression. The upper set of lines, three straight lines and one curved line, applies to tubes in flexure. The higher strengths at low R/t ratios reflect the additional strength due to the shape factor on bending for a tube (1.17). For larger R/t ratios the strength equations for axial compression also apply to bending members. For curved elements in bending members, experience with building sheathing products shows that their strength is lower than that for complete cylinders for low R/t ratios, and thus the dashed line on Figure CF.6.1 is used for this case.

The limitation of applicability of this Section to $R_b/t \leq 20$ for tubes with circumferential welds is the same as that of Section E.6.1.

F.7 Rods

The shape factors used for yielding and rupture of 1.30 and 1.42, respectively, are conservatively taken as the same as those for rectangular bars.

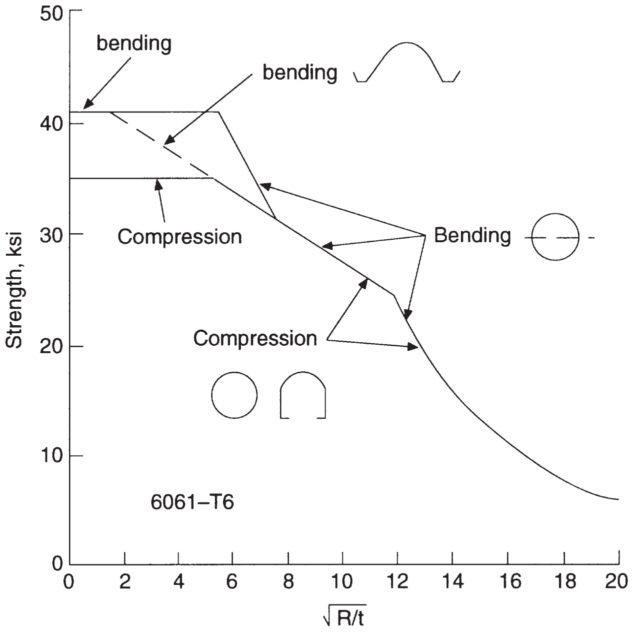


Figure CF.6.1
TUBES AND CURVED ELEMENTS
IN COMPRESSION OR BENDING

F.8 Elements of Flexural Members

F.8.1 Tension

F.8.1.1 Elements in Uniform Tension

The strength of elements in uniform tension is the same as the strength of members in axial tension addressed in Section D.2.

F.8.1.2 Elements in Flexure

The shape factors for flat elements in flexure are the same as the shape factors for solid rectangular shapes in F.4.1. Shape factors for aluminum are less than those for the rigid-plastic cases commonly used for mild steel because of the rounded stress-strain curves for aluminum alloys. The effect of alloy on shape factor is not very large, so only one set of shape factors is given.

Sharp (1973) tested beams with longitudinal and transverse welds in tension.

F.8.2 Compression

See Section E.4 for a discussion of the strength of longitudinally-welded elements.

F.8.2.1 Elements in Uniform Compression

The strength of beam elements in uniform compression is the same as the strength of column elements in uniform compression. These are given in Section B.5.4.

F.8.2.2 Elements in Flexure

The shape factors for flat elements in flexure are the same as the shape factors for solid rectangular shapes in F.4.1. Additionally, for flexural compression, buckling is addressed in Section B.5.5.

F.8.2.3 Alternate Compressive Flexural Strength

See the commentary to Sections B.5.4.6 and B.5.5.4.

F.8.3 Weighted Average Flexural Strength

Tests by Jombock and Clark (1968) of formed sheet beams were the basis for the weighted average compression and tensile bending strengths in *Specification* editions prior to 2005. Kim (2003) improved the weighted average method accuracy for a variety of members. The distance c for a tensile flange is the distance to its extreme fiber because tension fracture initiates there. The distance c for a compression flange is the distance to its centerline because buckling is based on the flange's average stress.

F.9 Welded Flexural Members

F.9.1 Flexural Members with Transverse Welds

For tubes with circumferential welds, Section F.8.2.1.6 only applies if $R_b/t \le 20$. If $R_b/t > 20$, Section F.8.2 is unconservative.

F.9.2 Flexural Members with Longitudinal Welds

The lateral-torsional buckling strength of flexural members with longitudinal welds is taken as a weighted average of the welded and unwelded strengths.

Chapter G Design of Members for Shear

G.1 General Provisions

The shear strength is limited only by the shear yield strength F_{sy}, and not the shear ultimate strength F_{su}. This simplification is used because for the alloy/temper products in this *Specification,* the shear ultimate strength divided by the ultimate safety factor (1.95) is at least 90% of the shear yield strength divided by the yield safety factor (1.65). Similarly, the shear ultimate strength multiplied by the ultimate resistance factor (0.75) is at least 90% of the shear yield strength multiplied by the yield resistance factor (0.90).

The strength of welded webs is based on shear fracture in the weld-affected area and the weighted average shear strength of the welded and unwelded zones. The shear ultimate strength is divided by 1.2 to provide a safety factor of 1.95 (= 1.2 × 1.65) or a resistance factor of 0.75 (= 0.90/1.2) once F_s has been factored by the safety and resistance factors given in Section G.1. Shear yielding in the weld-affected area is not considered to be a limit state, since the maximum shear stress would have to occur over a long enough length of the member to cause excessive deflection, and this is rare.

G.2 Members with Flat Webs Supported on Both Edges

The buckling strength of unstiffened flat webs is for a web with partial restraint against rotation at the attachment to the flanges. The corresponding value of the slenderness ratio is 1.25*b/t* based on Bleich (1952) and Gerard and Becker (1957). The buckling strength in the inelastic range was developed originally for shear buckling of tubes (Clark and Rolf (1964)) but also applies to flat elements in shear.

For webs with transverse stiffeners, the web's edges are assumed to be partially restrained against rotation, giving an equivalent slenderness ratio of

$$\frac{1.25a_1}{t\sqrt{1+0.7\left(\frac{a_1}{a_2}\right)^2}}$$

A stiffened flat web that has buckled in shear can continue to carry load by diagonal tension action in the web (Moore (1947)), but this is not accounted for in the provisions of Section G.2.

The required moment of inertia for the transverse stiffener is sufficient to limit local buckling of shear webs to the panels between stiffeners and to provide postbuckling strength in the web. This moment of inertia is multiplied by the ratio of the applied shear load to the shear load causing buckling to adjust the stiffener size for the actual load applied. These formulas were used in the specifications published by ASCE (1962a, 1962b), agree well with the results of tests by Moore (1942) and are conservative in comparison with the stiffener size theoretically derived by Cook and Rockey (1962). Hartmann and Clark (1963) and Sharp and Clark (1970) provide further background.

G.3 Round or Oval Tubes

The provisions for transverse shear of round or oval tubes are based on local buckling of cylinders subjected to torsion, which is addressed in Section H.2.1. Since torsion is usually constant along the cylinder length but transverse shear usually varies along the length, the transverse shear strength is taken as 1.3 times the torsion strength as suggested by Galambos (1998) in Section 14.3.4. This treatment is similar to AISC (2005).

In equation G.3-1, $V_n = F_sA_g/2$, it is assumed that the shear stress at the neutral axis $VQ/(Ib) = F_s$. For thin round tubes of radius R and thickness t, $I = \pi R^3t$, $Q = 2R^2t$, and $b = 2t$, which gives the shear stress at the neutral axis as $V/(\pi Rt) = V/(A_g/2)$.

Chapter H Design of Members for Combined Forces and Torsion

H.1 Members Subject to Flexure and Axial Force

Use of the interaction equation given in H.1 is predicated on a stability analysis performed in accordance with Chapter C. If the analysis is not performed in accordance with Chapter C, using the interaction equation given in Section H.1 can be unconservative.

H.2 Members Subject to Torsion

H.2.1 Round or Oval Tubes

The equation for equivalent *h*/*t* is based on the theoretical elastic buckling strength of cylinders in torsion. Tubes loaded in torsion are not as sensitive to the effect of initial imperfections in the geometry as are tubes loaded in axial compression. Battdorf, et. al. (1947) showed this gives good agreement with the results of tests on thin cylinders that fail in the elastic range, and Clark and Rolf (1964) showed this agrees well with experimental results in the inelastic stress range. The elastic buckling strength of cylinders in torsion matches AISC (2005) Specification Section H.3.1, since

$$\frac{\pi^2 E}{(1.25\lambda_t)^2} = \frac{1.23E}{\sqrt{L/D}(D/t)^{5/4}}$$

where $\lambda_t = 2.9(R/t)^{5/8}(L/R)^{1/4}$ and $R = D/2$

Sharp (1993) noted that the equivalent slenderness ratio for tubes can give very conservative results for long tubes with both longitudinal and circumferential stiffeners. Figure CH.2.1 shows the change in the coefficient in Equation H.2-2 with length of tube. A coefficient of 2.9 is specified for all cases (solid line in Figure CH.2.1). A more accurate and less conservative value for long tubes is less than 2.9 as illustrated by the dashed line in Figure CH.2.1. The ordinate in this figure is a rearrangement of Equation H.2-2. The addition of longitudinal stiffeners as well as circumferential stiffeners usually increases the shear strength of a tube compared to a tube with circumferential stiffeners only.

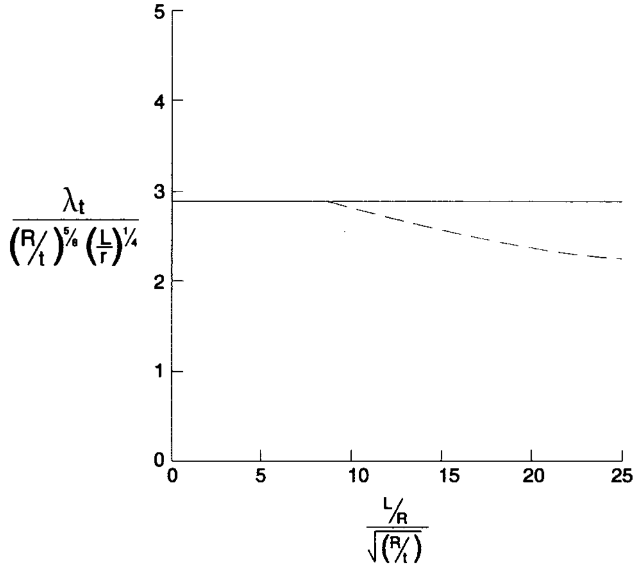


Figure CH.2.1
SHEAR BUCKLING OF TUBES WITH CIRCUMFERENTIAL STIFFENERS

H.2.2 Rectangular Tubes

Rectangular tubes were not specifically addressed before the 2010 *Specification.* The 2005 AISC *Specification* section H3.1(b) addresses rectangular tubes with equations that give the same limit state shear stress as the equations given in AISC *Specification* section G2.1(b)(i). H.2.2 matches the AISC approach, but uses the limit state shear stresses for aluminum webs given in the 2010 SAS Section G.2.1.

The torsion constant *C* for rectangular tubes of constant wall thickness *t* may be conservatively taken as

$$C = 2(b - t)(d - t)t - 4.5(4 - \pi)t^3$$

where

b = width of the tube
d = depth of the tube.

H.2.3 Rods

Since shear buckling cannot occur in a rod, Section H.2.3 simply uses shear yielding as the limit state shear stress for a rod.

H.3 Members Subject to Torsion, Flexure, Shear, and/or Axial Compression

H.3.1 Flat Elements

Equations H.3-1 and H.3-2 are documented in Galambos (1998) (equation 4.32).

H.3.2 Curved Elements

Equations H.3-3 and H.3-4 are documented in Galambos (1998) (equation 14.57), which is based on work by Schilling (1965).

Chapter J Design of Connections

J.1 General Provisions

J.1.3 Maximum Spacing of Fasteners

The maximum fastener spacing for tension member components are based on experience rather than tests or theory. Limiting the fastener spacing for tension member components reduces the chance of buckling if unanticipated compression acts on the member.

The maximum fastener spacing in built-up compression members is based on preventing buckling of the components between points of attachment.

J.2 Welds

Aluminum welded connection types include groove welds, fillet welds, plug and slot welds, and stud welds. Moore et al. (1971) and Sharp et al. (1982) documented strengths of aluminum welded connections.

J.2.1 Groove Welds

J.2.1.1 Complete and Partial Penetration Groove Welds

Groove welds are classified as either complete penetration or partial penetration for the purpose of determining the weld size. The method of classifying a groove weld is the same as that in AWS D1.2. Groove welds made with permanent backing have less fatigue strength than groove welds without permanent backing.

J.2.1.2 Effective Area

The definition of effective area matches that given in AWS D1.2.

J.2.1.3 Strength

Allowable stresses for groove welds for various combinations of base metals are given in Part VI, Table 6-1, and LRFD design stresses are given in Part VI, Table 6-3. The strength of a groove weld is usually governed by the strength of the base metal rather than the filler metal.

J.2.2 Fillet Welds

J.2.2.1 Effective Throat and Effective Length

The effective throat and effective length definitions match those in AWS D1.2-2008. Boxing is defined by AWS A3.0 as "the continuation of a fillet weld around a corner of a member as an extension of the principal weld." The effective throat of an equal leg fillet weld of size S is $0.707S_w$.

End-loaded fillet welds are oriented parallel to the stress in the member and transmit load to the end of an axially loaded member. Examples include longitudinally welded lap joints at the ends of axially loaded members and welds attaching bearing stiffeners. Examples of longitudinally loaded fillet welds that are not end-loaded include: a) welds that connect parts to form built-up members in which shear is applied to each incremental length of weld depending on the shear distribution along the member's length; b) welds attaching beam web connection angles and shear plates, because the flow of shear from the beam web to the weld is nearly uniform along the weld's length; and c) welds attaching stiffeners to webs, since the stiffeners and welds are not subject to calculated axial stress and only serve to keep the web flat.

J.2.2.2 Strength

Menzemer and Iasconne (2002) established the shear strengths of fillers 4047, 4643, and 5183. Nelson and Rolf (1966) established the shear strengths of the other fillers. They used the same test method to determine shear strength.

Allowable stresses for fillet welds for various combinations of base metals are given in Part VI, Table 6-2, and LRFD design stresses are given in Part VI, Table 6-4. The strength of a fillet weld is usually governed by the strength of the filler metal rather than the base metal.

J.2.3 Plug and Slot Welds

Plug and slot welds are primarily used to transmit shear in the plane of the weld. An example is a cover plate attached to a flange with plug welds. The definition of effective area and the limit on slot length match those in AWS D1.2 Section 2.5.

J.2.4 Stud Welds

Table J.2.2 and Table J.2.2M match AWS D1.2. The base metal thickness provisions match those in AWS D1.2 Sections 6.9.3 and 6.13.5.

J.2.5 Post-Weld Heat Treating

The strengths for 6005 and 6063 lighting pole assemblies artificially aged after welding are based on a report by the Texas Transportation Institute (1980).

J.3 Bolts

J.3.1 Bolt Material

a) ASTM F468, *Nonferrous Bolts, Hex Cap Screws, and Studs for General Use,* includes 2024-T4, 6061-T6, and 7075-T73 aluminum bolts and provides the strengths that are used in Table A.3.8. Bolt dimensions are given in Part VI, Table 5-4. ASTM F467, *Nonferrous Nuts for General Use,* includes 2024-T4, 6061-T6, and 6262-T9 aluminum nuts. Nut dimensions are given in Part VI, Table 5-5.

b) The AISC *Specification for Structural Steel Buildings* includes design rules for ASTM A307, A325, and A449 steel bolts. The Rockwell C35 hardness limit is intended to avoid hydrogen-assisted stress corrosion cracking of the bolt (see Section J.5.1 commentary). The zinc coating options match ASTM steel bolt specs A307, A325, A354, and A449, which specify that zinc coating be either hot-dip per A153 or mechanically deposited per B695.

c) ASCE 8-02, *Specification for the Design of Cold-Formed Stainless Steel Structural Members,* provides design rules for fasteners meeting ASTM F593, *Stainless Steel Bolts, Hex Cap Screws, and Studs.*

J.3.2 Holes and Slots for Bolts

It may be appropriate to limit hole diameter to 1/32 in. larger than the bolt diameter for bolts with a nominal diameter of 3/8 in. or less.

J.3.3 Minimum Spacing of Bolts

The minimum spacing requirement is intended to provide sufficient clearance for installation tools and washers.

J.3.4 Minimum Edge Distance of Bolts

Edge distance requirements ($2D$ for full bearing strength and a minimum of $1.5D$ with reduced bearing strength) have been selected so that for a single fastener, the block shear strength equals or exceeds the bearing strength. So for a single fastener, meeting the bearing requirements negates the need to check block shear.

Edge distance requirements apply to free edges of a part only, and not to the corner of a structural shape such as the heel of an angle.

J.3.5 Bolt Tension

The use of the root area for determining the tensile strength of aluminum fasteners rather than the slightly larger tensile stress area used for steel fasteners is based on Dewalt and Mack (1980). The root area is based on the nominal minor diameter of external threads ($D - 1.191/n$) given in ASME B1.1-1989, Unified Inch Screw Threads (reaffirmed in 2001) section 10.1.

Part VI, Table 5-3 gives tensile strengths for 2024-T4 and 7075-T73 bolts and cap screws.

The safety factor for bolt shear, bolt tension and rivet shear (2.34) is higher than for members (1.95) because it is preferable for the connections to be stronger than the members. If connections have greater strength, it is more likely that the structure will exhibit warning of an overload (e.g., excessive deflection and/or yielding of the members). Another reason for this higher safety factor is to lessen the likelihood that connection capacity-reducing conditions (e.g., limited amounts of corrosion or improper installation of fasteners) will have an adverse effect on the member's ability to reach its calculated nominal strength. Improper installation may include over- or under-tightening, missing nuts or washers, or presence of threads in the shear plane when this was not the design condition.

J.3.6 Bolt Shear

Rather than using approximate relationships between the threaded and unthreaded areas of bolts and different design stresses when threads are in the shear plane and when threads are not in the shear plane, this *Specification* uses the same design stress for both cases and adjusts the effective shear area appropriately.

Part VI, Table 5-3 gives shear strengths for 2024-T4 and 7075-T73 bolts and cap screws with threads in and threads not in the shear plane.

The root area term in equation J.3-2 matches the formula given in ASME B1.1 (1989).

J.3.7 Bolt Bearing

The limit state of bearing is reached when elongation of the fastener hole becomes excessive. Menzemer et al. (2001) established the bearing strength as $2F_{tu}$ for a load at which hole deformation is approximately $D/4$, where D is the nominal diameter of the bolt.

Sharp (1993) and the Department of Defense (1994) show that for ratios of edge distance to fastener diameter as small as 1.5, it is conservative to reduce the allowable bearing stress by the ratio of the edge distance to twice the fastener diameter. Moisseiff et al. (1944) demonstrated that a relatively even distribution of load among the fasteners is achieved before ultimate failure of mechanically fastened joints in structural aluminum alloys.

For countersunk holes, caution should be exercised when the depth of the countersink approaches the thickness of the part, creating a knife-edge on the hole which may be easily damaged.

J.3.8 Slip-Critical Bolted Connections

J.3.8.1 General

This Section is based on European specifications and testing conducted by Kissell and Ferry (1997). Aluminum slip-critical connections are included in Canadian, British, ISO, and Eurocode specifications. In the US, use of high strength steel bolts is governed by the Research Council on Structural Connections (RCSC) *Specification for Structural Joints Using ASTM A325 or A490 Bolts.* The RCSC *Specification* addresses the use of these high strength steel bolts to connect steel parts and so is modified here for connections using aluminum parts. All parts of the RCSC *Specification* not modified by the provisions of Section J.3.8 (for example, provisions on inspection) apply to aluminum slip-critical connections.

Slip-critical connections resist shear by friction between the faying surfaces of the connected parts, which are tightly clamped together by high strength steel bolts. Slip-critical connections are used when it is desirable to prevent movement of connected parts relative to one another. Such connections are useful for joints subjected to dynamic or fatigue loads, as well as joints in which both bolts and welds share the load, joints with oversize holes, and joints with slotted holes with loads not applied normal to the axis of the slot.

In addition to the requirements for bearing connections, slip-critical connections are subject to the additional requirement that the slip resistance of the joint be greater than the applied shear loads. The design strength of slip-critical connections cannot be greater than the design strength of the same connection designed as a bearing connection. The design strength of a slip-critical connection is limited to the lesser of the design strength of the bolt in shear and bearing and the slip resistance of the joint.

J.3.8.2 Material

Since hot-dip galvanizing may embrittle A490 bolts and galvanizing is required to discourage galvanic corrosion between the steel fastener and the aluminum parts, A490 bolts are not allowed in aluminum slip-critical connections.

The RCSC *Specification* limits the bearing stress under the bolt head in steel to 64 ksi for steel with a yield strength less than 40 ksi by requiring such steel with A490 bolts to have washers. The *Specification for Aluminum Structures* requires the use of washers under bolt heads and nuts, and bearing stresses under the washer can reach approximately 24 ksi (165 MPa) with A325 bolts. Therefore, aluminum slip-critical connections are limited to those alloys with a tensile yield strength of 15 ksi (105 MPa) or greater.

Thin parts, such as aluminum sheet and drawn tube, are effectively prohibited from slip-critical connections by bearing stress limitations on the sides of the hole.

ASTM A325 allows both hot-dip galvanizing and mechanical galvanizing of fasteners. A325 further requires that all components of a fastener assembly (bolt, nut, and washer) be coated by the same process, since mixing bolts and nuts galvanized by different processes may result in an unworkable assembly.

J.3.8.3 Holes

For convenience, nominal hole dimensions from the RCSC *Specification* are given in the Table CJ.3.1.

J.3.8.4 Design for Strength

Slip-critical connections must be designed assuming slip could occur, placing shear on the bolt and bearing on the sides of the hole. Bolt shear strengths are the same as in the RCSC *Specification.* Bolt design shear strengths should be reduced appropriately in long connections since bolts at the end of such connections bear a higher shear force than bolts near the middle of the length of these connections. (The RCSC *Specification* requires shear strengths be reduced by 20% in connections whose length between extreme fasteners measured parallel to the line of force exceeds 50 in. (1300 mm)).

J.3.8.5 Design for Slip Resistance

Slip coefficients are given for two contact surfaces: roughened aluminum on roughened aluminum, and roughened aluminum on zinc-rich painted steel. Kissell and Ferry (1997) tested these surfaces in accordance with the test method given in the RCSC *Specification* for both slip and creep. Slip coefficients for other surfaces may be determined by testing in accordance with the RCSC *Specification.*

Luttrell (1999) and Fortlin, et al. (2001) showed that bolt tension is not significantly affected if the temperature changes from the installation temperature.

Tests of mill finish aluminum surfaces degreased and dried have generally achieved relatively low coefficients of friction.

J.3.8.6 Washers

Washers are required under all bolt heads and nuts. This requirement is intended to minimize galling of the outer ply of aluminum and creep relaxation of bolt tension.

Table CJ.3.1
HOLE DIMENSIONS FOR SLIP-CRITICAL JOINTS

	Hole Dimensions (in.)			
Bolt Diameter (in.)	**Standard (Diameter)**	**Oversized (Diameter)**	**Short Slotted (Width × Length)**	**Long Slotted (Width × Length)**
½	9/16	5/8	9/16 × 11/16	9/16 × 1 ¼
5/8	11/16	13/16	11/16 × 7/8	11/16 × 1 9/16
¾	13/16	15/16	13/16 × 1	13/16 × 1 7/8
7/8	15/16	1 1/16	15/16 × 1 1/8	15/16 × 2 3/16
1	1 1/16	1 ¼	1 1/16 × 1 5/16	1 1/16 × 2 ½
≥1 1/8	*d* + 1/16	*d* + 5/16	(*d* + 1/16) × (*d* + 3/8)	(*d* + 1/16) × (2.5*d*)

J.3.9 Lockbolts

A lockbolt assembly includes a pin, which is similar to a bolt, and a collar, which performs the function of a nut. The collar is swaged onto locking grooves on the pin. Lockbolts are available in carbon steel, stainless steel, and aluminum.

J.4 Rivets

J.4.1 Rivet Material

ASTM B 316, *Aluminum and Aluminum-Alloy Rivet and Cold-Heading Wire and Rods,* provides the strengths that are used in Table A.3.9.

J.4.2 Holes for Cold-Driven Rivets

Holes for cold-driven rivets are sized so that the rivet completely fills the hole when driven.

J.4.4 Minimum Edge Distance of Rivets

See Section J.3.4.

J.4.5 Rivet Tension

Rivets are sensitive to grip (the thickness of the parts joined) and hole size, since these parameters affect the fastener's head dimensions, unlike bolted installations. If the hole is too large or mislocated, or if the parts are slightly thicker or thinner than the thickness the rivet was selected for, the rivet head formed during installation is imperfect. These effects are greater on tensile strength than shear strength, since unless the rivet falls out of the connection, shear can still be resisted, but in tension the parts can begin to disengage without a proper head on both sides of the parts joined. The tensile strength of riveted connections, therefore, can vary significantly.

J.4.6 Rivet Shear

The shear strength of aluminum rivets is based on the rivet filling the hole so the effective shear area of the rivet is the nominal hole diameter.

J.4.8 Blind Rivets

Installing blind rivets requires access to only one side of a connection.

J.5 Tapping Screws

Screwed connection provisions are based on Peköz (1990), who considered over 3500 tests on light-gage steel and aluminum connections worldwide. ECCS (1987) and BSI (1987) were also considered.

Proper installation of screws is important to achieve satisfactory performance. Power tools with adjustable torque controls and driving depth limitations are usually used.

Screw connection tests used to formulate the provisions included single fastener specimens as well as multiple fastener specimens. However, it is recommended that at least two screws should be used to connect individual elements. This provides redundancy against under torquing, over torquing, etc., and limits lap shear connection distortion of flat unformed members such as straps.

The safety factor for screwed connections in building-type structures is 3.0, which matches AISI (2001). The safety factor for screwed connections in bridge structures is 3.0(2.20/1.95) = 3.38, rounded to 3.5. The safety factor for screw bearing is consistent with the safety factor for screw shear and tension.

J.5.1 Screw Material

The material for screws used to connect aluminum parts is selected to meet strength and corrosion resistance considerations. Steel screws with a Rockwell hardness of C35 or greater may suffer hydrogen-assisted stress corrosion cracking (HASCC) where exposed to certain dissimilar metals, moisture, and tensile stress due to installation or loading. For this reason, steel screws with a Rockwell hardness of C35 or greater are not permitted. Aluminum and austenitic stainless steel screws do not experience HASCC. When fasteners will not be exposed to contact with liquid water or humidity near the dew point, certain other steels, with appropriate hardness, and appropriately coated and/or plated are also acceptable. An example is 430 stainless steel, which has a nominal composition of 16% chromium.

J.5.2 Holes for Screws

This *Specification* requires that the nominal diameter of unthreaded holes for screws shall not exceed the nominal diameter of the screw by more than 1/16 in. (1.6 mm). Many designers specify that the nominal diameter of unthreaded holes for screws shall not exceed the nominal diameter of the screw by more than 1/32 in. (0.8 mm).

Table J.5.1 is based on AAMA (1991) Table 20, which was used for the hole sizes used for the pull-out testing that Section J.5.5.1.1 pull-out strengths are based on.

Table J.5.2 is based on AAMA (1991) Table 21, which was used for the hole sizes used for the pull-out testing on which Section J.5.5.1.1 pull-out strengths are based.

J.5.3 Minimum Spacing of Screws

See Section J.3.3.

J.5.4 Minimum Edge Distance of Screws

See Section J.3.4.

J.5.5 Screwed Connection Tension

The smallest screw head or washer size allowed is 5/16" since the diameter of a hex washer head for a No. 8 screw (the smallest screw size allowed by this *Specification*) is 5/16".

J.5.5.1 Pull-Out

J.5.5.1.1 Screws in Holes

The equations for pull-out are derived from research conducted by AAMA (2000), including over 400 pull-out tests. These equations are based on three regions of behavior: yield (circumferential stretching and bending of the aluminum around the screw), shearing of the internal threads in the hole, and a transition region between yield and shearing. For most cases they are less conservative than the pull-out equation in the *Specification's* 6th edition ($P_{not} = 0.85 t_c\ DF_{tu2}$), especially for UNC threads in aluminum parts thicker than 0.084 in. (2.1 mm). Pull-out strengths are a function of the type of thread: coarse (UNC) or spaced. A UNC thread is often referred to as a "machine" thread, and a spaced thread screw is termed a "sheet metal" screw.

Internal thread stripping areas A_{sn} are given in Part VI Table 5-6 for Class 2B UNC threads.

J.5.5.1.2 Screws in Screw Slots

Menzemer (2008) tested spaced thread screw types and machine thread screw types to develop Equation J.5-7. The average of all spaced thread tests was 0.2% greater than the strength given by Equation J.5-7, and the average of all machine thread tests was 4.2% greater than the strength given by Equation J.5-7. Because both spaced threads and machine thread pull-out strengths matched Equation J.5-7 well, this *Specification* does not provide different strengths for the different screw types.

J.5.5.2 Pull-Over

Sharp (1993) provided the pull-over strength equation for non-countersunk screws. Screws may be placed through the valley or the crown of corrugated roofing and siding. (See Figure CJ.5.1). A coefficient of 0.7 is used when the connected parts are not in contact, such as for fastening through the crown of roofing when a spacer block is not used between the roofing and the structural member supporting the roofing. The test strengths of such screwed connections are more variable than those with the connected parts in direct contact at the connection such as the fastener through the valley in Figure CJ.5.1.

Alternate pull-over strengths are given for screws in tight-fitting holes based on tests conducted by LaBelle and Dolby (2009). In these tests, screws had hex heads with integral washers. Screw nominal diameters were 0.164, 0.190, 0.216, and 0.25", and part nominal thicknesses were 0.04, 0.06, 0.09, and 0.125". The holes were "free fit" with the following nominal sizes:

Screw Size	Hole Diameter (in.)	Drill Size
8	0.177	16
10	0.201	7
12	0.228	1
¼	0.266	H

These hole sizes average 0.013" larger than the screw diameter, smaller than the 0.062" oversize the *Specification for Aluminum Structures* allows. The average ratio of predicted strength (using *Specification* equation J.5-9) to test strength was 0.83 with a coefficient of variation of 7.3%.

The equation for the pull-over strength of countersunk screws is based on over 200 tests by LaBelle and Dolby (2004) using 5 different flathead screw sizes, 6 sheet thicknesses, and 2 alloy-tempers. Testing was limited to commonly used screws with 82 degree nominal angle heads, so the equation is not known to apply to other head angles.

Variation in actual diameters of hand-drilled countersunk holes can have a significant effect on pull-over strength. Caution should be used to avoid excessive oversizing of countersunk holes. Oversizing should be limited so that the top of the screw head is no more than the lesser of $t_1/4$ and 1/32 in. (0.8 mm) below the top of the sheet.

J.5.5.3 Screw Tension

The tensile strength of aluminum screws is given in Part VI Tables 5-1 and 5-2.

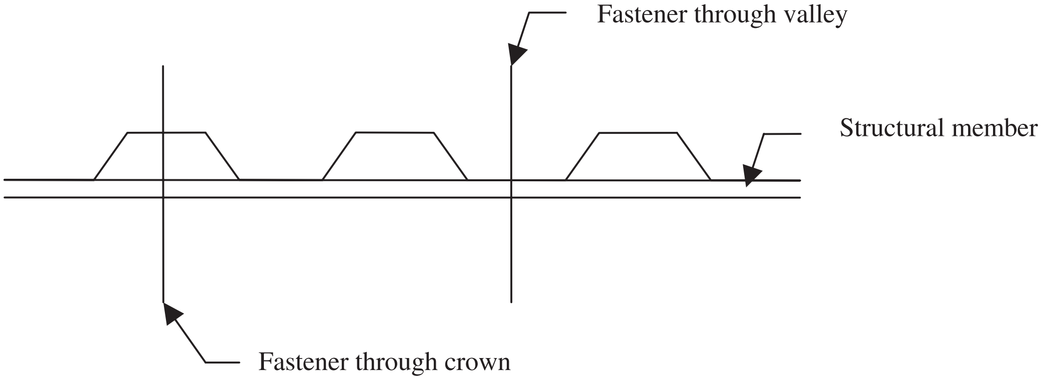


Figure CJ.5.1
FASTENERS IN ROOFING

J.5.6 Screwed Connection Shear

Screwed connections loaded in shear have limit states of screw shear, block shear rupture (see Section J.6.3), tilting, and bearing failure of the joined materials.

J.5.6.1 Screw Bearing

Based on limited testing, it appears that the bearing force exerted on a connected part by a screw should be limited to that which produces a hole elongation of $D/8$ to avoid threads disengaging from the sides of the hole. Therefore, testing is recommended to establish the bearing strength of screwed connections that are subjected to both bearing and tensile loads.

J.5.6.2 Screw Tilting

Screw tilting occurs when the part under the screw head is thicker than the part beneath it. The shear force on the joint causes the axis of the screw to tilt toward the plane of the connected parts and the screw threads to tear out of the lower sheet.

J.5.6.3 Screw Shear

The shear strength of aluminum screws is given in Part VI Tables 5-1 and 5-2.

J.6 Affected Elements of Members and Connectors

J.6.2 Strength of Connectors in Shear

The resistance factor for shear yielding of connectors (1.00) is higher and the safety factor (1.50) is lower than for shear yielding of members. This is because shear yielding of connectors is unlikely to produce significant deformation of the structure as a relatively small portion of the structure is comprised of connectors.

J.6.3 Block Shear Strength

The block shear rupture strength is based on work by Menzemer (1999) and is the same as in the AISC *LRFD Specification for Structural Steel Buildings* 1993 edition, Section J4.3. Marsh (1979) also studied this issue.

J.7 Bearing Strength of Flat Surfaces and Pins

The bearing strength for flat surfaces and elements with pins in holes is 2/3 the bearing strength for elements with fasteners in holes. This is because bearing on flat surfaces and on elements with pins can tolerate less deformation than a fastener in a hole at the bearing limit state.

J.8 Flanges and Webs with Concentrated Forces

J.8.1 Crippling of Flat Webs

The formulas given in this Section are based on Sharp (1993). The crippling strength is a post-buckling strength.

J.8.2 Bearing Stiffeners

This *Specification* addresses bearing stiffener size by requiring that the stiffener be sized for the bearing load as a member in axial compression. If the stiffener is also being used as a shear stiffener, it must also meet the requirements of Section G.2.2.

J.8.3 Combined Crippling and Bending of Flat Webs

The formulas given in this Section are empirical, based on Sharp (1993).

J.9 Roofing and Siding Connections

J.9.3 Fasteners in Laps

The minimum size of #12 screws or 3/16 in. (5 mm) diameter rivets is specified in end laps and side laps to give neat, weather-resistant closures. In many cases, the primary, sheet-to-support fasteners will give satisfactory closures at the endlaps, but in side laps additional fasteners should be used if the joint does not interlock.

Chapter L Design for Serviceability

L.1 General Provisions

This chapter addresses preserving a structure's appearance, maintainability, durability, occupants' comfort, or function. Specific limits on parameters (for example, deflection) are not provided, since these depend on the type of structure and its use.

L.2 Camber

Camber should be measured without load acting in the camber plane. This may be achieved by measuring camber with a beam resting on a flat surface parallel to the camber plane.

L.3 Deflections

Members and structures deflect under load. For example, the lateral deflection of a building under wind load is called drift.

If the compressive stress exceeds the elastic local buckling stress F_{cr}, the full section is not effective in resisting deflection. This *Specification* only allows this if the element strength is based on post-buckling strength as it is in Sections B.5.4.1, B.5.4.2, B.5.4.3, B.5.5.1, and B.5.5.3. Reduced effective section provisions do not apply to B.5.4.4, for example, since this section does not allow post-buckling strength for such elements (supported on both edges and with an intermediate stiffener). The method used to account for the effect of local buckling on the post-buckling behavior of structural members is to consider that at stresses above the local buckling stress only part of the buckled element is effective in carrying load. Sooi and Peköz (1993) and Jombock and Clark (1968) documented this approach.

AAMA TIR A11 limits deflections of components that support glass or similar brittle materials. Some building codes also limit deflections.

L.4 Vibration

Vibration of aluminum structural members can cause fatigue failures. Vibrations may be caused by cyclically applied loads from machinery, by wind or other fluids moving over the structure, or by traffic on a bridge. When the frequency of the applied load is close to the natural frequency of the structure, the amplitude of the vibrations can be large, especially for lightly damped structures. The amplitude of the vibrations can be minimized by adjusting the stiffness of the structural components so that the natural frequency of the structure is less than half or more than twice the frequency of the applied loads or by sufficiently dampening the structural movement.

L.5 Wind-Induced Motion

Wind on round tube members can cause motion of the members due to vortex shedding, by which regular impulses transverse to the wind direction are caused by the shedding of vortices on alternating sides of the member. Sharp (1993) gives the frequency of vortex shedding as

$$f = SV/d$$

where f = vortex shedding frequency
V = wind velocity
d = outside diameter of tube
S = Strouhal number = 0.2 for tubes.

If this frequency is near the natural frequency of the tube and sufficient damping is not provided, wind-induced motion will be large. (See Section L.4).

L.6 Expansion and Contraction

Aluminum's coefficient of thermal expansion is approximately 13×10^{-6}/°F (23×10^{-6}/°C). For structures exposed to ambient temperature fluctuations, provision for thermal movement such as expansion joints may be required to limit stresses.

L.7 Connection Slip

Slip-critical connections are addressed in Section J.3.8.

Chapter M Fabrication and Erection

M.1 Layout

M.1.1 Punch and Scribe Marks

Hole centers are commonly located by punching, and cutoff lines are often scribed. Center punching and scribing should be avoided where such marks would remain on fabricated material if appearances are a concern.

Punched or scribed layout marks serve as fatigue crack initiation sites and thus are prohibited for material designed for fatigue.

M.2 Cutting

M.2.1 Methods

The heat of plasma arc and laser cutting tends to produce edge cracking, especially in heat treatable alloys (2xxx, 6xxx, and 7xxx series).

M.2.2 Edge Quality

AWS D1.2 has additional requirements for edges that will be welded.

M.2.3 Re-entrant Corners

Fillets reduce stresses at re-entrant corners of parts. The proper fillet radius varies depending on the part and its use. AWS D1.1:2004, the steel structural welding code, Section 5.16, requires a minimum fillet radius of 1 inch. AWS D1.2:2008, the aluminum welding code, Section 4.11.6, requires ½ in. for statically loaded members and ¾ in. for cyclically loaded members. In *Specification* Table 3.1, the smallest radius for attachments for which fatigue categories are provided is 2 inches. Since this *Specification* applies to parts of any size, it is impractical to specify a minimum radius.

M.3 Heating

Alloys 535.0, 5083, 5086, 5154, and 5456 have magnesium contents greater than 3%. When such alloys are held within the temperature range of 150°F (66°C) to 450°F (230°C), they may "sensitize" and subsequently suffer exfoliation and stress corrosion cracking. The length of time in this temperature range determines the degree of sensitization to exfoliation and stress corrosion cracking.

The strength of tempered metal can be reduced by exposure to elevated temperature processes (such as factory paint curing, firing of porcelain enamel coatings, and hot forming). See the commentary to Section A.3.1.1.

M.4 Holes

M.4.1 Fabrication Methods

The prohibition against punching parts thicker than the hole diameter is to guard against break-out at the back side of the hole.

M.5 Bending

Minimum bend radii for 90° cold forming of sheet and plate are given in Part VI Table 3-1 for various alloys and tempers. These radii are approximate and are a function of the direction of the bend line with respect to the rolling or extruding direction. Cracking of heat treated alloys is more readily avoided with the bend line perpendicular to the rolling or extrusion direction, while the opposite is true for non-heat treatable alloys.

M.6 Finishes

M.6.1 Where Protective Coating Is Required

Examples of protective coatings include anodizing, painting, and Alclad products.

The American Architectural Manufacturers Association offers these Voluntary Specification, Performance Requirements and Test Procedures for coating aluminum:

AAMA 2603 Pigmented Organic Coatings on Aluminum Extrusions and Panels
AAMA 2604 High Performance Organic Coatings on Aluminum Extrusions and Panels
AAMA 2605 Superior Performing Organic Coatings on Aluminum Extrusions and Panels.

Where water is allowed to stand between aluminum parts in contact, oxidation called water staining may result. While this oxidation has little or no effect on material strength and will not progress after the water is removed, it is unsightly and difficult to remove. It can be prevented by keeping aluminum dry or out of contact with other aluminum parts when moisture can be present.

M.6.2 Surface Preparation

Proper surface preparation is required for good paint adherence.

M.6.3 Abrasion Blasting

Abrasion blasting can be used to clean material or finish the surface. Abrasive media includes steel grit, silica sand, aluminum oxide, crushed walnut shells, or coal slag. Peening can be used to improve fatigue strength by introducing compressive stress near the surface and is typically achieved with steel or stainless steel shot.

Residual stresses from blasting or peening can curl thin material. Abrasion blasting may also reduce the thickness of material. Consideration should be given to the effect on strength if the thickness is reduced by more than standard mill tolerances for the material.

M.7 Contact with Dissimilar Materials

Isolators such as Teflon, neoprene, and 300 series stainless steel may be placed between aluminum and other materials to prevent contact. The isolator should be nonporous to avoid trapping water or other substances in the joint and compatible with both the aluminum and the dissimilar material in the intended service.

M.7.1 Steel

Coating the steel is usually more effective than coating the aluminum to prevent galvanic corrosion between aluminum and steel.

M.7.2 Wood, Fiberboard, or Other Porous Materials

Wood that has been treated with preservatives is usually corrosive to aluminum. Chromated copper arsenate (CCA) treated wood is about twice as corrosive to aluminum as non-treated wood. Residential use of CCA treated wood ended in 2003 and was replaced by alkaline copper quaternary (ACQ) treated wood, which is about four times as corrosive to aluminum as untreated wood.

M.7.3 Concrete or Masonry

To avoid staining and surface corrosion, mill finished aluminum and anodized aluminum should be protected from uncured concrete, mortar, and similar alkaline substances and muriatic acid used in cleaning concrete and masonry.

Masonry products designed to remain at a relatively low pH during and after curing (such as magnesium phosphate grout, which does not exceed a pH of 8.5) do not corrode aluminum.

M.7.4 Runoff from Heavy Metals

Heavy metals can cause deposition corrosion of aluminum. Copper is the most common of these of metals used in construction, but terne-coated steel (which has a lead/tin coating) may also have this effect.

M.8 Fabrication Tolerances

The *L*/960 straightness tolerance was chosen so that the reduction in buckling strength versus a perfectly straight member is no greater than about 20%. The standard tolerance for some mill products does not meet the *L*/960 straightness tolerance for fabricated members required here (Aluminum Association (2009)). (An example is T6511 extrusions with wall thicknesses less than 0.095 in.). Such members may require additional straightening or tighter tolerance specifications to meet the requirements of this Section.

M.9 Welding

AWS D1.2 provides requirements for qualifying, fabricating, and inspecting aluminum welds. Welding is done in the shop or in an enclosure because shielding gas must cover the arc and wind can disrupt the shield.

Groove welds (Figure CM.9.1) are utilized for butt joints. Groove welds are shaped for ease of root penetration, to allow for less dilution of the filler by the base metal (where hot cracking is a problem), or to permit a desirable sequence of weld bead depositions when welding in other than flat positions. Fatigue strength can be significantly increased by removing weld reinforcement.

Fillet welds (Figure CM.9.2) are used to join surfaces to each other in lap, T, or corner joints; the filler usually determines the strength of these joints. A sounder and more economical structure results from using continuous welds rather than intermittent ones. While an intermittent weld may reduce welding time, filler wire consumption, heat input and/or distortion, it may produce unfavorable local stress concentrations. The possibility for poor weld quality and end craters increases with the repeated stopping and restarting of the welding. Since the cost of fillet welds is a function of the square of their size, large intermittent welds are not as efficient in carrying loads as small continuous fillets. Intermittent welds also make a structure more susceptible to moisture infiltration, which may ultimately lead to corrosion.

Fillet welds exhibit different strengths depending on the geometry of the part and the type of loading on the weld. The filler shear strengths in the *Specification* are based

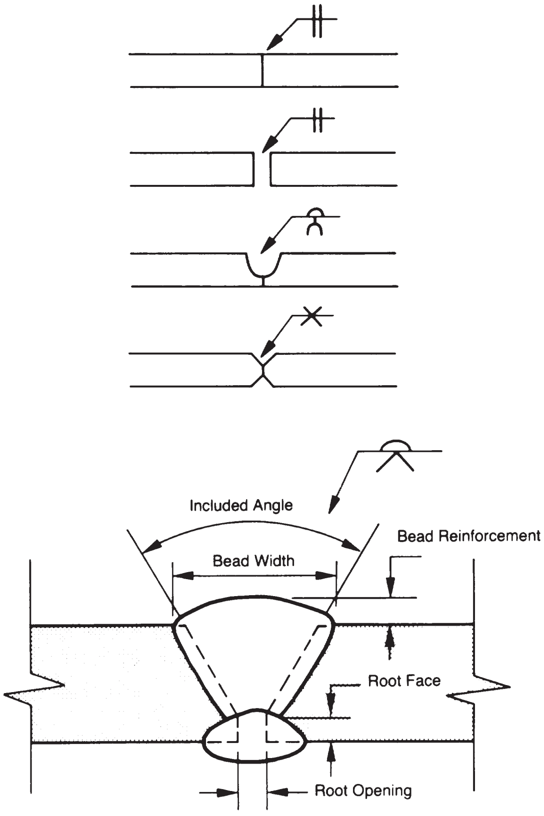
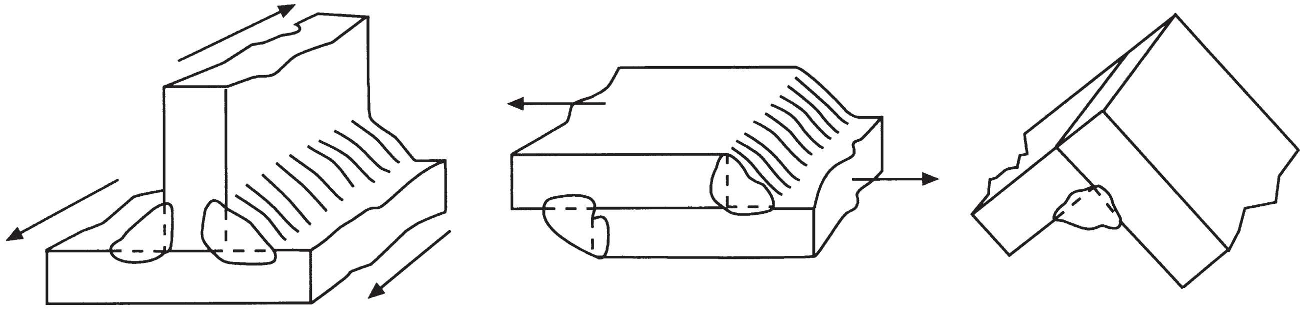


Figure CM.9.1



a. Longitudinal Fillet **b. Transverse Fillet** **c. Corner Weld**

Figure CM.9.2

on tests of longitudinal fillet welds (see Figure CM.9.2a), which results in pure shear on the throat of the weld. Transverse welds (Figure CM.9.2b is one type) can have higher strengths in some cases, since the stress on the weld throat is a combination of shear and tension. This strength increase, however, is not recognized in the *Specification.*

There are many joint details that can be utilized to improve weld performance:

1) A butt joint between different thicknesses of metal should have the thicker one beveled to match the thinner one (Figure CM.9.3). This helps balance the heat sink for uniform melting and good fusion, and reduces the stress raiser caused by change in thickness.
2) Welds may have lower strength than the base metal (e.g., welds in 6061-T6 alloy). One way to reduce the effect this has on load carrying capacity is by locating the welds in areas of low stress. Beams can be fabricated by welding together longitudinal extrusions with joints located in webs near the neutral axis (Figure CM.9.4). Since the web is often much thinner than the flanges, the amount and cost of welding are reduced.
3) Rectangular doubler plates welded on four sides have transverse welds which reduce the member's strength. If only the sides of the doubler are welded, the longitudinal welds may become so highly stressed that they fail. When a doubler plate is necessary, it should be diamond shaped (Figure CM.9.5), avoiding a sudden cross-sectional change. No welding should be done across the ends. The doublers should be as wide as possible, consistent with leaving room for a fillet weld on each side. The doubler length (l) should be greater than its width (w) by a ratio of at least 3 to 1, which orients the fillet welds nearly parallel to the stress direction.
4) When stiffening a panel or member, care should be taken to avoid abrupt changes in cross sections. Reinforcing stiffeners should have tapered ends (Figure CM.9.6) to avoid fatigue cracks at the end of the stiffener.
5) A common design issue is joining members at corners to give an economical, structurally sound, and aesthetically pleasing connection. Figure CM.9.7 illustrates corner details. Double fillets or bends to allow a butt or a lap joint should be used.
6) When sheets are to be welded to extruded members, an attempt is sometimes made to use a joint opening between sheets and make a groove weld (Figure CM.9.8). In effect,

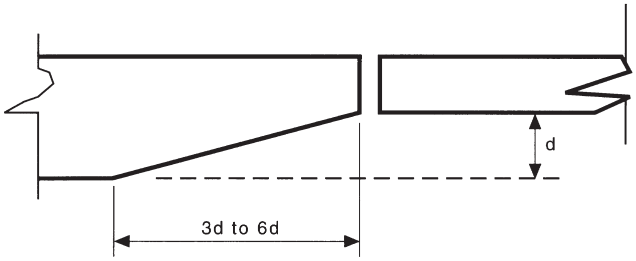


Figure CM.9.3

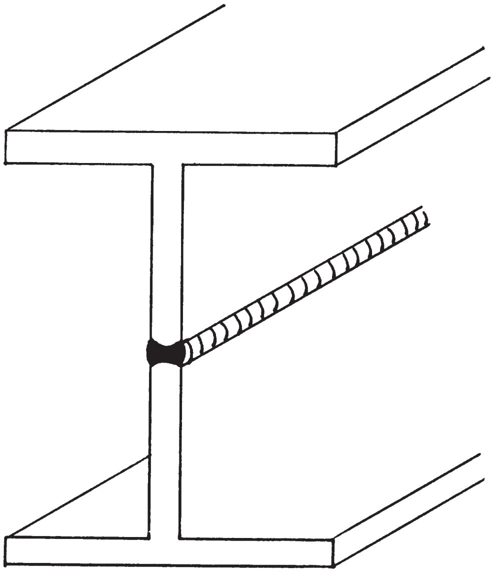


Figure CM.9.4

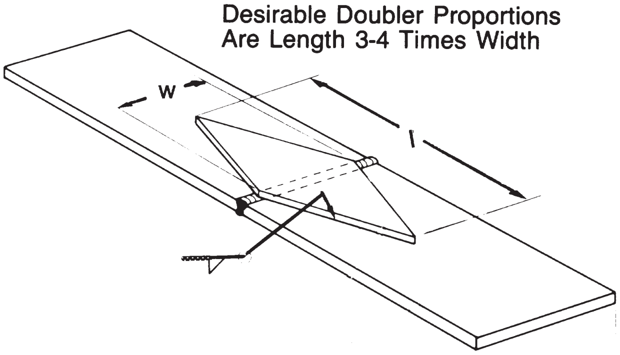


Figure CM.9.5

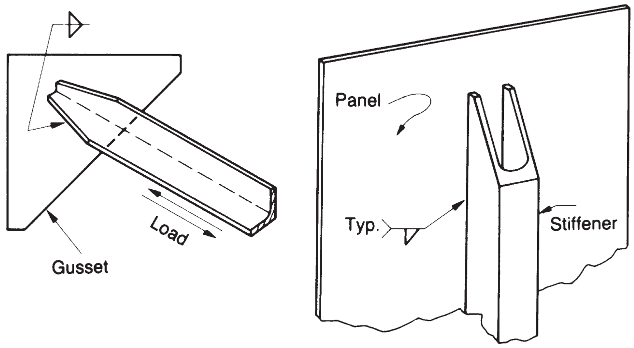


Figure CM.9.6

what is desired resembles a slot weld, which seldom proves practical. The joint fit and the welding procedure are both critical if the sheet edges are hot enough to melt back from the joint when the welding current is high enough to penetrate the extrusion. Therefore, conventional lap joints are recommended instead for this application.

M.10 Bolt Installation

Snug tightness, a condition achieved when all plies in a joint are in firm but not necessarily continuous contact, can usually be attained by a few impacts of an impact wrench or the full effort of a person using an ordinary spud wrench.

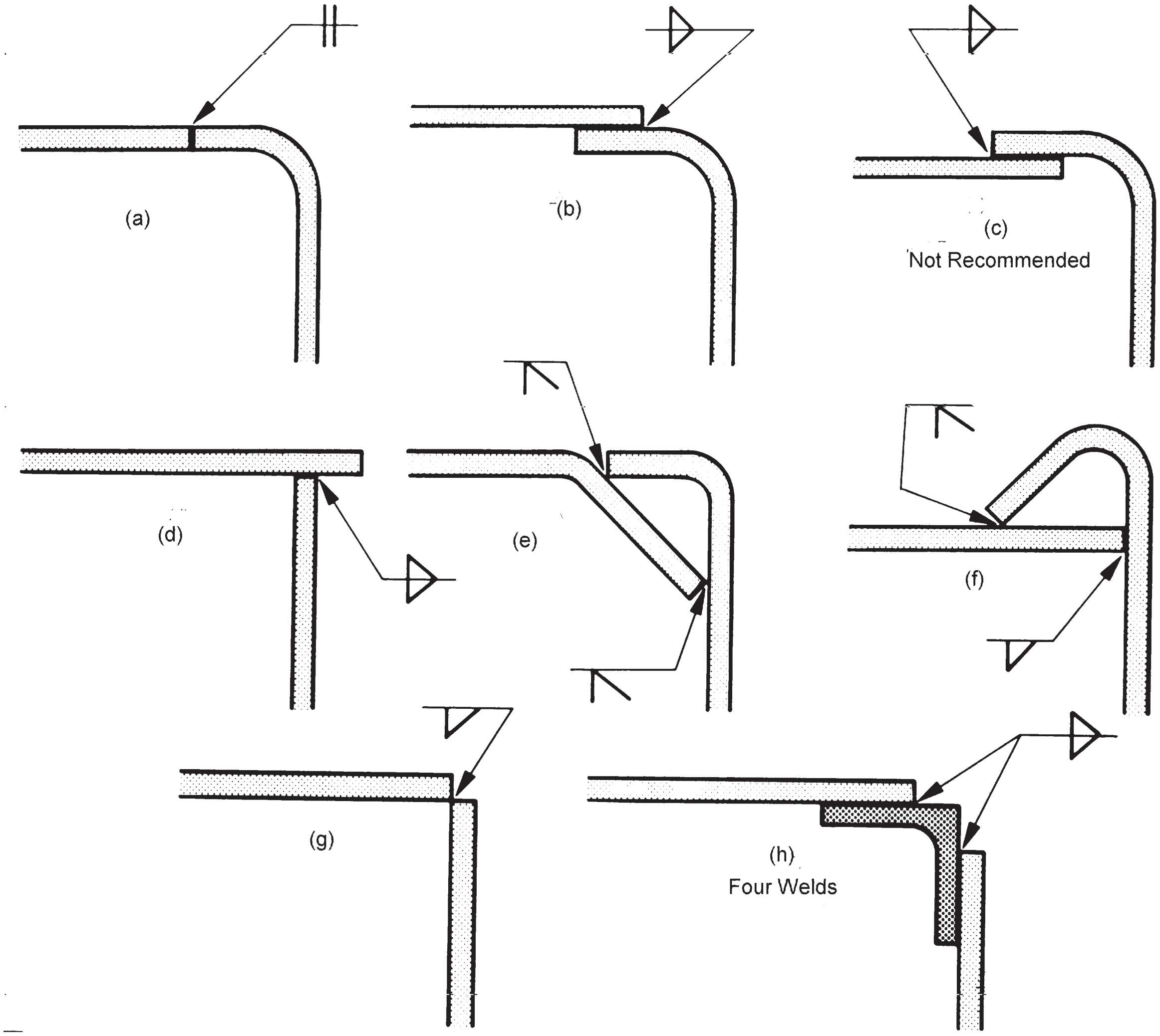


Figure CM.9.7

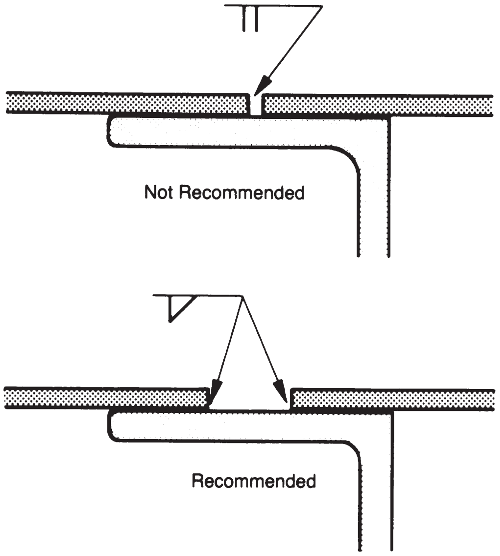


Figure CM.9.8

A specific clamping force is not necessary in non-slip-critical connections because the design accounts for parts slipping relative to each other.

No rules for determining the tightening torque for aluminum bolt bearing connections have been established because test results vary widely depending on the friction developed in the threads and other bearing surfaces. A recommendation sometimes made for establishing a tightening torque for aluminum bolts is as follows: Tighten several bolts of a given size and type to the breaking point under the same conditions of lubrication as will be encountered on the job and use 70% or 80% of the lowest torque obtained from the tests. The 70% value should be used for bolts that may need to be removed occasionally, while the 80% value applies to permanent bolts. Lubricating the threads and bearing surfaces is helpful.

These recommendations for tightening may be modified for bolts or other threaded parts that carry fluctuating axial tensile loads that can cause fatigue failures. Under these conditions, the tightness (initial axial tensile load) should be slightly more (about 5%) than the maximum tensile load on the bolts during service. There are many devices available to prevent loosening, and guidance is available for their use (AAMA (1991)). Lock washers are commonly used; less common are locking inserts built into the nut threads.

For slip-critical bolted connections, minimum bolt tensions from the RCSC *Specification* are given in the Table CM.10.1.

Turn-of-nut tightening of slip-critical connections is performed by bringing the assembly to a snug tight condition and then applying a prescribed number of turns of the nut. Aluminum's lower modulus of elasticity versus steel means more turns would be needed for aluminum assemblies than for steel assemblies if the bolt tension at the start of turn-of-nut tightening were the same for both steel and aluminum assemblies. However, the flexibility of aluminum parts enables them to be brought closer to full contact by snug tightening than steel, resulting in higher bolt tension in aluminum assemblies at the beginning of turn-of-nut tightening. The net effect, confirmed by testing, is that aluminum assemblies require approximately the same number of turns as steel assemblies after the snug tight condition is attained to reach the bolt tension prescribed above.

Table CM.10.1
MINIMUM BOLT TENSION FOR SLIP-CRITICAL JOINTS

Bolt Diameter (in.)	A325 Bolt Tension (k)
½	12
⅝	19
¾	28
⅞	39
1	51
1⅛	56
1¼	71
1⅜	85
1½	103

Galvanizing increases the friction between the bolt and nut threads and makes torque-induced tension more variable, but lubrication both reduces the torque and makes it more consistent. Therefore, ASTM A 325 requires that a galvanized bolt and lubricated galvanized nut be assembled in a steel joint with a galvanized washer and tested in accordance with ASTM A 563 by the manufacturer prior to shipping to assure that the fastener can be rotated beyond the required rotation from the snug-tight condition without breaking. Since some lubricants are water soluble, galvanized bolts and nuts should be shipped in plastic bags in wood or metal containers.

M.11 Riveting

M.11.1 Driven Head

Rivet head styles are shown in the 2005 ADM, Part VII, Table 5-6. Part VII, Table 5-13 provides maximum rivet grips for given lengths for flat driven heads.

M.11.2 Hole Filling

Recommended hole sizes for cold-driven rivets are shown in the 2005 ADM, Part VII, Table 5-8. Rivet lengths are given in Part VII, Table 5-12 for various grips and diameters.

M.12 Erection Tolerances

Erection tolerances are often expressed in terms of tolerances on the plumbness and levelness of structural members. The erection tolerances specified on the construction documents must match the tolerances used for the stability analysis performed in accordance with Chapter C.

Appendix 1 Testing

1.1 General Provisions

An example of a nationally recognized accreditation service is the International Code Council's (ICC) International Accreditation Service (IAS). The ICC publishes the *International Building Code.*

1.3 Number of Tests and the Evaluation of Test Results

1.3.1 Tests for Determining Mechanical Properties

Equation 1.3-1 is from Goepfert (1994). Values for K are taken from Juran (1988) and are one-sided factors affording 95% confidence that at least 99% of the population would fall above the predicted minimum value. Johnson (1994) provides K values for several n values greater than 100, including $K = 2.326$ for n = infinity. (See Section A.3.2 for discussion of the statistical basis for mechanical properties of aluminum alloys).

1.3.2 Tests for Determining Structural Performance

Provisions in Section 1.3.2 are similar to those in AISI (2001).

1.4 Testing Roofing and Siding

Deflection limits for roofing and siding tests should be selected accounting for the possibility of ponding.

Appendix 3 Design for Fatigue

3.1 General Provisions

Sanders and Day (1983) studied fatigue behavior of aluminum weldments. Sanders and Fisher (1985) provided the fatigue provisions that appeared in the 1986 *Specifications for Aluminum Structures.* These provisions were subsequently revised based on work by Menzemer (1992) on full scale welded beams and by Kosteas, et al. (1985).

The major factors affecting fatigue behavior are the number of stress cycles, the magnitude of the stress range, and the type and location of the member or detail. Fatigue cracks generally grow perpendicular to the plane of maximum stress. This *Specification* uses a nominal stress range determined by elastic analysis. The effect of stress concentrations are accounted for by the proper selection of fatigue details. Many other factors, including temperature, corrosive substances, weld defects, and post-weld mechanical treatment can have an effect on fatigue strength but are not addressed by this *Specification.*

If information on the number of stress cycles is available for similar structures of materials other than aluminum, the same values may be used for aluminum structures.

Wind-induced vibrations of undamped structures or components can cause large numbers of cycles and high stresses and thus should be avoided. Vibration dampers may be used to limit wind-induced vibrations. Vibration of structures caused by unbalanced forces from machinery can be minimized by the use of properly designed vibration mounts and proper design of the structure. If the loading frequency is between 1/2 and 2 times the natural frequency of a structure, damping should be considered (Sharp (1993)).

The fatigue strength of mechanically fastened connections with a stress ratio less than or equal to zero is based on Atzori, et al. (1997), who considered data from about 750 tests of bearing and friction joints with a wide variety of conditions. The data used to determine the fatigue strength of joints with a stress ratio of zero conservatively include numerous tests with a stress ratio of 0.1.

Azzam and Menzemer (2006) established the fatigue strength for detail category F1.

The use of S-N curves given in the *Specification* is the most common but is only one of four methods of designing for fatigue. The others are hot spot (addressed by Sharp (1996a, 1996b)), strain-life, fracture mechanics, and good practice design methods.

Fatigue-resistant joints can be made using gradual changes in geometry of components and joints and avoiding areas of concentrated load and stress. Because most fatigue failures initiate at areas of localized high stress, particularly joints, these details should be designed carefully. Two approaches to address this are given below.

- Joints may be eliminated by using extrusions, thus removing sites for fatigue crack initiation. Sometimes the designer can locate joints or discontinuities in areas of low stress to improve fatigue resistance.
- Joints can be enhanced to improve fatigue strength. These include shaping the weld toes and peening the edges of the welds. Adhesives can be employed in mechanically fastened (and spot welded) joints. Tests are required to establish fatigue strength in such cases. See Section M.6.3 for the use of peening to improve fatigue life.

3.2 Constant Amplitude Loading

The allowable stress range is based on a 95% confidence for 97.7% probability of survival. The constant amplitude fatigue limit was assumed to occur at 5×10^6 cycles for each detail except category F1. This *Specification's* static strength provisions limit the allowable stress range for low numbers of cycles.

3.3 Variable Amplitude Loading

Actual load histories are frequently more complicated than the constant amplitude loading addressed in Section 3.2. Section 3.3 provides a design method for the variable amplitude loadings experienced by many structures. This equivalent stress method is based on nominal stress ranges, linear damage accumulation, and no sequencing effects. The rainflow method (Fuchs and Stephens (1980), Smith, et al. (1988)) is a commonly used cycle-counting method.

The equation for the equivalent stress range is derived from Miner's Rule when the S-N curve is a straight line in log-log space. Miner's rule is

$$\frac{\Sigma n_i}{N_i} \leq 1.0 \tag{3.3-1}$$

where

n_i = number of cycles of the ith stress range

N_i = number of cycles constituting failure at the ith stress range.

When this fraction approaches unity, some of the details within the group have begun to fail. Miner's rule may be used over the equivalent stress range to assess the remaining life of an existing structure or when fatigue data is not linear in the log(stress)-log(life) space.

Allowable stress ranges for variable amplitude fatigue are determined in the same manner as for constant amplitude fatigue except that the constant amplitude fatigue limit is not used because data for variable amplitude loads show continuing strength decrease at long lives. Structures subjected to variable amplitude loading may not exhibit a fatigue limit because a crack can be initiated by the higher stress cycles of the spectrum and propagate at stresses below the fatigue limit.

There also may not be a fatigue limit in mechanical connections that fail by fretting, whereby relative movement of the connected parts causes part wear to occur. Tests may be required to evaluate the possibility of fretting failures.

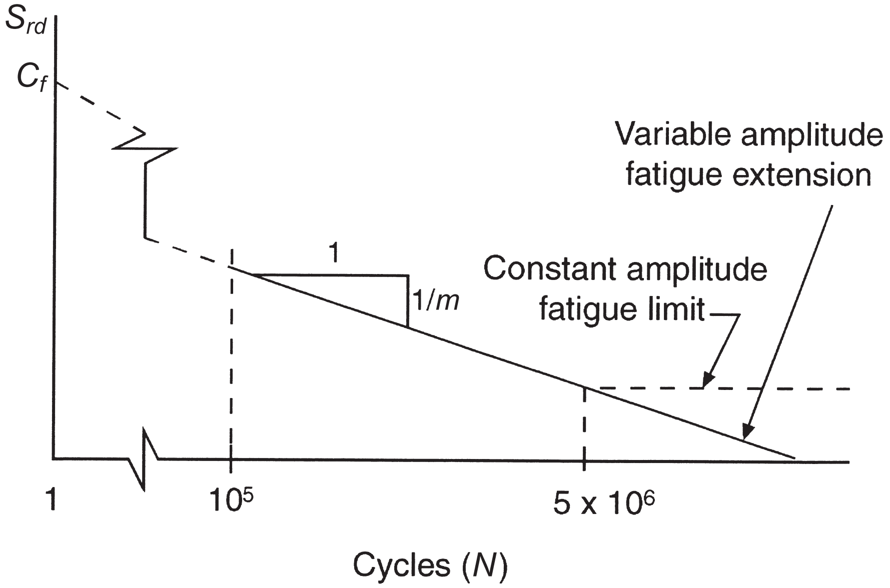


Figure C3.2
SCHEMATIC FATIGUE CURVE

Appendix 4 Design for Fire Conditions

4.1 General Provisions

This appendix is similar to the AISC (2005) appendix on design for fire conditions. While aluminum is noncombustible as determined by ASTM E 136 tests, aluminum strengths and stiffness are less at elevated temperatures than at room temperature.

4.1.3 Load Combinations and Required Strength

The analysis must be performed in accordance with the requirements of Chapter C.

4.2 Design for Fire Conditions by Analysis

4.2.3 Material Properties at Elevated Temperatures

Eurocode 9 Part 1-2 provides additional information on aluminum material properties at elevated temperatures.

4.2.3.1 Mechanical Properties

The modulus of elasticity E_m at elevated temperatures is not a function of time at the elevated temperature. The moduli given by Table 4.1 are from Kaufman (1998).

Strengths at elevated temperatures are a function of time at the elevated temperature. The strengths given in Table 4.2 are from Kaufman (1999) for 10 hours at the elevated temperature. Kaufman provides test data for additional alloy-tempers.

4.2.3.2 Thermal Expansion

The coefficient of thermal expansion increases with temperature and does not vary significantly by alloy.

4.2.3.3 Specific Heat

Specific heats increase with temperature.

Aluminum Standards and Data (2009) Table 2.3 provides thermal conductivities for aluminum alloys at room temperature. Thermal conductivities vary by alloy and temper and increase with temperature.

Appendix 5 Evaluation of Existing Structures

5.4 Evaluation by Load Testing

The procedure for evaluating existing structures by load testing is intended to produce no permanent deformation. The *International Building Code* 2009 section 1714.3.2 requires that existing structures be load tested to 2 times the design load. This would exceed safety factors used for aluminum building structures (1.65 on yield and 1.95 on collapse). The test load is therefore limited to a factored load of $1.0D + 1.4L$, which is approximately 85% of the LRFD load combination $1.2D + 1.6L$. ACI uses 85% of their factored loads. The load factor for wind, snow, or rain loads should be the same as for live load when determining the test load.

Appendix 6 Design of Bracing for Columns and Beams

6.1 General Provisions

The provisions of this appendix are based on recommendations given in the SSRC Guide (Ziemian (2010)), and are similar to those in the AISC *Specification for Structural Steel Buildings* Appendix 6. See the commentary to AISC Appendix 6 for additional information on these provisions.

Bracing requirements are based on a member with an initial out-of-straightness due to lateral forces and fabrication or erection tolerances of *L*/500. If initial out-of-straightness is greater than *L*/500, the brace force should be increased in direct proportion to the increase in initial out-of-straightness. Torsional bracing of beams is based on an initial twist of 1°.

Appendix 6 addresses two types of bracing systems: relative and nodal. These bracing systems are described in the SSRC Guide.

6.2 Column Bracing

For nodal bracing, the required bracing stiffness is a function of the number of braces. The required bracing stiffness given in Section 6.2 is conservative, being for the case of many braces, and is twice the stiffness required for one intermediate brace.

6.3 Beam Bracing

Beam bracing must control twist of the section, but need not prevent lateral displacement. Both lateral bracing attached to the compression flange of a beam or torsional bracing can control twist.

6.3.2.1 Nodal Bracing

If $\beta_{sec} < \beta_T$, β_{Tb} determined from Equation 6-10 is negative, indicating that torsional beam bracing will not be effective due to inadequate web distortional stiffness.

6.4 Beam-Column Bracing

The bracing requirements for compression and those for flexure are superimposed to arrive at the requirements for beam-columns.

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Aluminum Design Manual

PART III

Design Guide

III
Design Guide

TABLE OF CONTENTS

1. Introduction

This part of the *Aluminum Design Manual* addresses aluminum structural design issues not addressed in Part I, the *Specification for Aluminum Structures*.

The strength equations given in Part I may be applied to the design of any structural components, including buildings, bridges, ships, rail cars, automobiles, trucks, highway structures, and machinery. For example, the equations for a column given in the *Specification* apply equally to a column for a patio roof, a member in a latticed roof, a strut in a rail car or automobile, a member in a bridge truss, and a stanchion or pillar in a ship.

2. General Considerations

2.1 Aluminum's Attributes

Aluminum has many attributes that make it a cost-effective structural material. Most applications make use of a favorable life cycle cost, which includes costs for material, fabrication, erection or installation, operation, maintenance, and disposal.

For example, aluminum is the principal material in aerospace structures, primarily because of its high strength-to-weight ratio. The density of aluminum is about ⅓ that of steel, and aluminum alloys have strengths similar to those of construction steels. Aluminum aerospace structures are cost effective because smaller engines and less fuel are needed during service compared to those required for heavier structures.

Aluminum structures generally weigh ⅓ to ½ those of steel (see Section 2.3). Light weight and corrosion resistance are the major factors for the selection of aluminum for trucks, automobiles, and rail cars.

Aluminum's excellent corrosion resistance (see Section 6) helps reduce maintenance costs. Aluminum's corrosion resistance and its appearance, bare or finished, are major factors in its use in buildings. Many aluminum structures, such as light poles, overhead sign trusses, latticed roofs, and bridges do not require painting because of aluminum's corrosion resistance.

2.2 Alloy Selection

Sheet, plate, extrusions, forgings, and castings are made of aluminum. Alloys and tempers with both good strength and corrosion resistance are available. Aerospace alloys are generally not used for other types of structures because their combination of specialized properties results in relatively higher costs than that of other alloys. Examples of some of the common alloys and tempers used for each product are given in the following table.

Product	Application	Alloys
Sheet and Plate	Building	3105-H25, 5052-H34, 3004-H16
	Heavy Duty Structures	5083-H116, 5086-H116, 6061-T6
Extrusions	Building	6063-T5, 6063-T6
	General Purpose	6061-T6
Forgings	Wheels	6061-T6
Castings	General Purpose	356.0-T6, A356.0-T6
	High Elongation	A444.0-T4

2.3 Comparing Aluminum and Steel

Aluminum structural design is very similar to that for steel and other metals. Because many engineers are more familiar with steel than aluminum, aluminum and steel are compared in Table 2-1, taken from Sharp (1993).

Because of the difference in properties (modulus, for example) an aluminum design should be different than that for steel in order to use material efficiently. Figure 2-1 shows the relative weights of aluminum and steel box beams with the same bending strength and deflection. The yield strength of the two materials is the same. The aluminum part weighs about 50% of the steel part when its size is about 1.4 times that of steel. Other configurations provide less weight savings. Where deflection and fatigue considerations control the design, such as in bridge girders, automotive frames and

Table 2-1
COMPARING ALUMINUM AND STEEL

Property	Steel	Aluminum	Importance for Design
Modulus of elasticity	29×10^3 ksi	10.1×10^3 ksi	Deflection of members Vibration Buckling
Weight per volume	0.284 lb/in^3	0.10 lb/in^3	Weight of Product, Vibration
Thermal expansion	7×10^{-6}/°F	13×10^{-6}/°F	Thermal expansion Thermal stress
Stress-strain curves	Varies	Varies	Depends on alloys Steel often has higher strength and elongation at room temperature Aluminum has better performance at low temperatures
Fatigue Strength	Varies	Varies	For joints, aluminum has about ⅓ to ½ the fatigue strength as steel for same detail
Corrosion resistance	Needs protection	Often used unpainted	Aluminum usually is maintenance free Aluminum is non-staining
Strain rate effects on mechanical properties	High strain rates increase properties—varies with type of steel	Much less change in properties compared to steel	Need to use dynamic properties for high-strain rate loadings

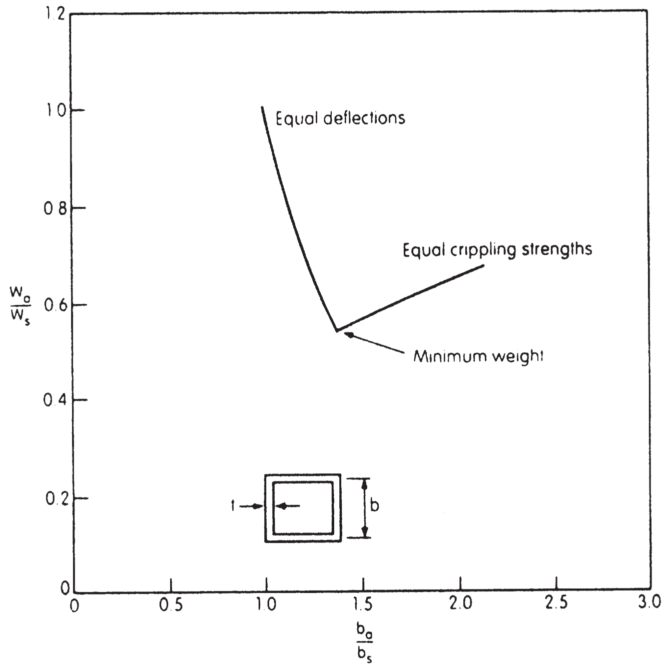

Figure 2-1
MINIMUM WEIGHT OF SQUARE TUBULAR SECTIONS

other transportation vehicles, aluminum structures weigh about half that of steel structures. For structures controlled by static strength, such as automobile hoods and deck lids and some building components, aluminum structures weighing about ⅓ that of steel have been achieved. Such structures are designed for aluminum and do not have the same dimensions as the steel structure.

Figure 2-2 shows fatigue strengths for aluminum and steel for groove welds (a Category C detail). For long lives the fatigue strength of aluminum groove welds is about 40% that for steel. The difference is smaller at shorter lives.

In efficient designs, aluminum components are different from steel components for the same loading. Aluminum beams should be deeper than steel beams. The spacing of stiffeners on aluminum elements should be smaller than for steel. These geometrical differences will help meet deflection requirements for aluminum components and reduce stresses, helping with fatigue requirements.

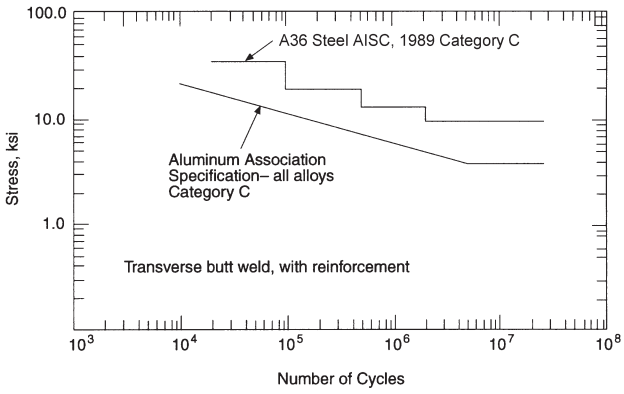

Figure 2-2
FATIGUE DESIGN CURVES
FOR ALUMINUM AND STEEL

2.4 References

The following references are additional sources of information on aluminum structural design. References marked * are available from the Aluminum Association (www.aluminum.org/bookstore). References marked ** are available for free download from the Aluminum Association at www.autoaluminum.org.

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3. Structural Issues not Addressed in the *Specification for Aluminum Structures*

3.1 Ductility

The accepted measure of ductility of aluminum alloys is fracture toughness and many high strength aluminum alloys used in aerospace applications have been evaluated as summarized by the Aluminum Association (1987). The ductility of alloys included in the *Specification* (non-aerospace alloys) is generally not a design issue for wrought products. The best proof of adequate ductility of alloys is the satisfactory service in buildings, bridges, automobiles, trucks, and rail cars. Menzemer (1992) showed that in laboratory fracture tests the normalized resistance curves (same fatigue strength) of parts made from 5456-H116 were higher than those of A36 steel at temperatures from −200 to +75 °F. Sharp (1993) provides additional information on the toughness of aluminum alloys.

Welded strengths can be increased by welding in the solution heat-treated temper and then aging or by welding and then solution heat treating and aging. Light pole manufacturers typically use post-weld heat treatment. The ductility of transversely welded structures is usually reduced by post-weld heat treatment because the width of the zone of lower strength material is decreased (plastic deformation may be confined to a narrow zone). Post-weld heat treatments require careful evaluation of strength, ductility, and corrosion resistance implications.

3.2 Shear Diaphragms

Shear diaphragms are efficient in carrying shear loads. Corrugated panels can be used for a building's side or roof. The strength and stiffness of a corrugated panel subjected to shear depend on the alloy, configuration of the corrugation, size of the panel, and the type and configuration of the fastening to the framing members. Sharp presents the following design considerations:

1. Overall shear buckling of the panel may control strength. An equivalent slenderness ratio is defined for this mode of failure that is used with the buckling equations for shear.
2. Local buckling of the shear elements of the corrugations is given by the equations for unstiffened webs.
3. Failure of the corrugations and of the fastening at the supports must be calculated. Local failure of the corrugations at their attachment to supporting members can occur particularly if only part of the shape is connected.
4. Shear deflection of the panel is much larger than a flat panel of the same size. The major factors are size of panel, shape and thickness or corrugation, and the type and arrangement of the fastenings. Sharp (1993) provides equations of behavior for several standard corrugated shapes.

The Metal Construction Association's *Primer on Diaphragm Design* (2004) addresses aluminum diaphragms. Sooi and Peköz (1993) provide additional information on building diaphragms and their interaction with building frames.

3.3 Pipe Bursting Pressure

Sharp (1993) gives the bursting pressure of aluminum pipe as:

$$P = \frac{2tF_{tu}K}{D - 0.8t}$$

Where:

P = bursting pressure
t = pipe wall thickness
F_{tu} = tensile ultimate strength
$K = 0.73 + 0.33F_{ty}/F_{tu}$
D = pipe outside diameter
F_{ty} = tensile yield strength

Aluminum pipe applications may be governed by standards for that use. For example, aluminum pipe used in chemical plants and petroleum refineries is often designed in accordance with ASME B31.3, which provides a slightly different strength equation and safety factors appropriate to such applications.

3.4 Biaxial and Triaxial Stresses

The Aluminum *Specification* predates finite element analysis (FEA) and doesn't directly address all issues that arise from such analyses. For example, the *Specification* provides design stresses for prismatic members primarily under uniaxial stress, such as columns. FEA, on the other hand, can provide triaxial stresses by reporting, in addition to longitudinal stresses, through-thickness and transverse stresses. Many FEA programs calculate a von Mises stress (explained below) from the triaxial stresses at a given element.

Yielding occurs in ductile materials like aluminum when

$$(f_1 - f_2)^2 + (f_2 - f_3)^2 + (f_3 - f_1)^2 \geq 2\, F_{ty}^2$$

where f_1, f_2, f_3 = principal stresses (the normal stress on each of three orthogonal surfaces such that the shear stresses on the surfaces are zero)
F_{ty} = tensile yield stress

This equation is called the von Mises criterion or distortion energy criterion. It predicts that yielding will occur when the distortion energy equals the distortion energy in an axially loaded member at yield. The above equation is for the general triaxial stress state. If stresses are biaxial, $f_3 = 0$, and the equation above predicts yielding when

$$(f_1 - f_2)^2 + f_2^2 + f_1^2 \geq 2 F_{ty}^2$$

For convenience, the von Mises stress is defined from the von Mises criterion as

$$\sqrt{\frac{(f_1 - f_2)^2 + (f_2 - f_3)^2 + (f_3 - f_1)^2}{2}}$$

so that it may be compared directly to the yield stress to determine if yielding will occur. In the biaxial stress state, the von Mises stress becomes

$$\sqrt{f_1^2 - f_1 f_2 + f_2^2}$$

The von Mises criterion is used in the Aluminum *Specification* to determine the shear yield strength of aluminum alloys, since there is no established test method to measure shear yield strength. In the case of pure shear, the shear stresses in a biaxial stress element are τ and $-\tau$. Mohr's circle can be used to show that the principal stresses f_1 and f_2 are, then, also τ and $-\tau$, so the von Mises stress is

$$\sqrt{\tau^2 - \tau(-\tau) + \tau^2} = \tau\sqrt{3}$$

When the von Mises stress equals F_{ty}, yielding occurs, so shear yield τ_y is

$$\tau_y = \frac{F_{ty}}{\sqrt{3}}$$

Local yielding in a member may not limit its usefulness if the amount of material that yields is small or positioned so as to have only a negligible effect on the shape and load-carrying capacity of the member. Where yielding is a limit state, the von Mises stress should be limited to the yield strength of the material.

3.5 Aluminum Composite Material (ACM)

The 2009 *International Building Code* (IBC) Section 1402.1 defines metal composite material (MCM) as "a factory-manufactured panel consisting of metal skins bonded to both faces of a plastic core." Panels with aluminum skins are called aluminum composite material (ACM) (see Figure 3-1). The IBC also defines a metal composite material system as "an exterior wall covering fabricated using MCM in a specific assembly including joints, seams, attachments, substrate, framing and other details as appropriate to a particular design." However, ACMs are not limited to exterior applications.

IBC Section 1407 provides requirements for two uses of MCM: one as exterior wall finish, and the other as architectural trim. Section 1407.4 requires that MCM exterior walls be designed for IBC Chapter 16 wind loads for components and cladding. Section 1407.5 requires that test results or engineering analysis be submitted to the building official to demonstrate this. IBC also specifies fire-resistance requirements that apply to both MCM uses.

ACM panels must be designed to meet deflection limits as well as provide sufficient strength for wind loads.

Typical ACM properties

Property	Value	Units
coefficient of thermal expansion	13×10^{-6}	/°F
available thicknesses	3, 4, and 6	mm
skin thickness	0.020	in.

Manufacturers provide additional information on load-span-deflection, dimensional tolerances, section modulus, stiffness, weight, thermal resistance, sound transmission, and fire resistance.

In a similar product, an aluminum-elastomer sandwich beam, the components comprising the structural elements also act together creating a combined strength and other characteristics that are greater than the sum of the parts. The composite beam may have to resist stresses due to a temperature gradient through the section as well as stresses from wind and dead loads. The amount of composite action can be determined by analysis (AAMA (1990)) or testing.

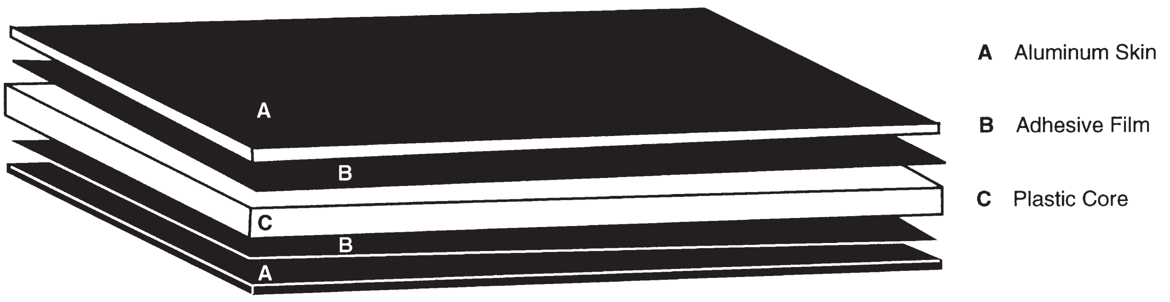


Figure 3-1
SANDWICH PANEL

4. Adhesive Bonded Joints

An adhesive can be defined as a substance capable of holding materials, similar and dissimilar, together by surface attachment. The critical substrate surfaces can be held together by chemical and/or mechanical adhesion at the interfacial layer of contact between surfaces (D.A.T.A. (1986)).

4.1 Advantages and Disadvantages

Shields (1970) and Thrall (1984) address advantages and disadvantages of adhesives. Some advantages of adhesive bonding are:

- Ability to bond a variety of materials that may exhibit differing coefficients of thermal expansion, moduli, thickness, etc., with proper joint design and material selection.
- Improved cosmetics of the finished product by the elimination of protruding mechanical fasteners, such as rivets or bolts.
- Excellent strength to weight ratio in comparison to other joining methods.
- Good joint stiffness and fatigue performance, with appropriate choice of adhesive.
- Elimination of stress concentrations inherent to mechanical fastening methods, and a more uniform stress distribution over the bonded surface area.
- Adaptable to many production processes because of the variety of forms (pastes, films, emulsions, etc.) and methods of application of adhesives.

The advantages of adhesive bonding are most evident when joining relatively thin materials and components. The cost advantages and joint efficiencies decrease as the members become thicker.

Some disadvantages of adhesive bonding are:

- Expert joint design is critical in order to minimize peel and/or cleavage stresses.
- Temperature limitations may restrict the use of many adhesives from high temperature applications.
- Adhesives require surface pretreatment of the aluminum unless the adhesive manufacturer recommends that no pretreatment is necessary. Even with this recommendation, the durability required for the application should be verified.
- Difficulties in inspecting for initial bond integrity and an insufficient understanding of the effects of in-service damage on subsequent bond performance limit confidence in adhesive bonding as a primary structural joining method.

4.2 Adhesive Selection

Literally thousands of commercial adhesives are available. In order to select the proper adhesive for a particular application the user needs a systematic approach to adhesive selection. Major areas to address are:

- Substrates
- Pretreatment
- Application of adhesive
- Fabrication process
- Service environments
- Design

4.3 Types of Adhesives

Kinloch (1987) identified two groups of adhesives: thermoplastics and thermosets. Thermoplastics are materials which can be repeatedly softened by heat and hardened by cooling to ambient temperature. Thermosets are materials that undergo chemical reactions initiated by heat, catalyst, UV light, etc. Thermosets are generally more durable than thermoplastics.

From the two groups of adhesives extend several classes of adhesives, which include anaerobic, contact, cyanoacrylate, film, hot melt, one-part and two-part. Anaerobic adhesives are generally esters or acrylics in which, upon the restriction/lack of air/oxygen, curing of the adhesive initiates. Anaerobic adhesives can also be cured by UV exposure. Contact adhesives are coated to both substrate surfaces, and a solvent is allowed to evaporate before assembly of the substrates. Cyanocrylates are known as instant cure adhesives. They are derivatives of unsaturated acrylates which cure at room temperature without the aid of a catalyst. Films are uniform layers of adhesives that are generally rolled onto coils. Films can be supported (with reinforcing fibers), unsupported, heat-activated, or pressure-sensitive. Hot melts are generally solvent-free thermoplastics, which are solids at room temperature but soften and flow at heat activation temperature. Upon cooling the hot melt regains its structural strength. One-part adhesives are usually 99–100% solid systems. This class of adhesives includes epoxies, moisture activated silicones, and polyimides which can be waterborne or organic solvent based. Two-part epoxies and acrylics are generally cured at room temperature or accelerated with heat.

4.4 Surface Pretreatments

A surface pretreatment prior to bonding is usually necessary in order to achieve long-term bond strength of aluminum substrates, although in some cases an adhesive manufacturer may state that their adhesive requires no surface pretreatment or that their adhesive is chemically incompatible with the proposed pretreatment. Many aluminum surface pretreatments have been examined to determine the best adhesive substrates for bonding. It is commonly accepted that chemically pretreating the surface yields more durable bond strength than mechanically abrading the aluminum surface. Some of the most popular chemical pretreatment systems to improve the adhesion of aluminum are degreasing, acid etching, and phosphoric acid anodizing. The adhesive manufacturer's recommendations for surface preparation should be followed.

4.5 Joint Design

The decision to use adhesive bonding must consider joint geometry, the nature and magnitude of loading, the properties of the adhesive and the members to be joined, failure modes, and ease and reliability of manufacturing. Adapting a joint design intended for other joining methods often results in ineffective designs. The design must also consider the assembly scheme including needs for surface pretreatment, part tolerances, and fixturing.

The stresses present in adhesive-bonded joints are classified based on loading: normal, shear, peel, and cleavage (Figure 4-1). Cleavage and peel conditions describe a combination of normal and shear stresses specific to these two loading conditions. Cleavage stresses are concentrated on one side of the joint, while peel loads can occur with flexible members (Kinloch (1987)). Though technically different, tensile stresses normal to the bond line are also referred to as peel stresses in the literature. Because adhesives perform best when subjected to compressive and shear loads, joint design should distribute the loads in the adhesive layer as a combination of compressive and shear stresses to avoid tensile, cleavage and peel loadings.

There are four basic types of joints: angle, tee, butt, and surface or lap joints (Figure 4-2). In service, these joints may be subjected to the types of stresses mentioned in the previous paragraph. Most practical adhesive joint designs can be classified as variations of lap joints. Lap joint configurations are usually preferred because they require little or no machining. The use of overly complex configurations for low loads results in unnecessarily expensive designs. On the other hand, simple configurations are unacceptable if smooth uninterrupted surfaces are required, if high stresses are present in the bond, or if high loads must be sustained.

In single lap joints that are not supported or restrained against joint rotation, bending within the joint and at the ends of the overlap causes locally high transverse tensile stresses in the bond. In joints that are designed to prevent or minimize joint rotation, the bond strength can exceed the full nominal strength of the members.

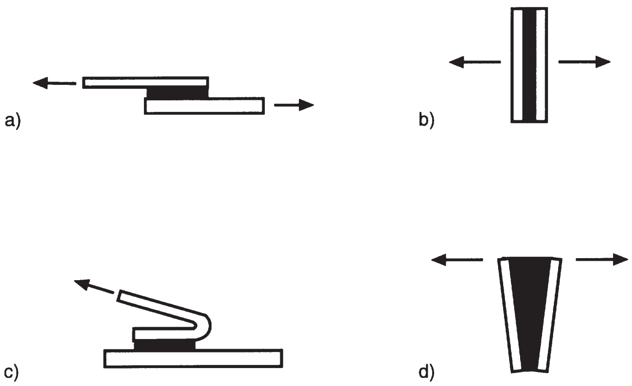


Figure 4-1
TYPES OF STRESSES: A) SHEAR; B) TENSION; C) PEEL; D) CLEAVAGE

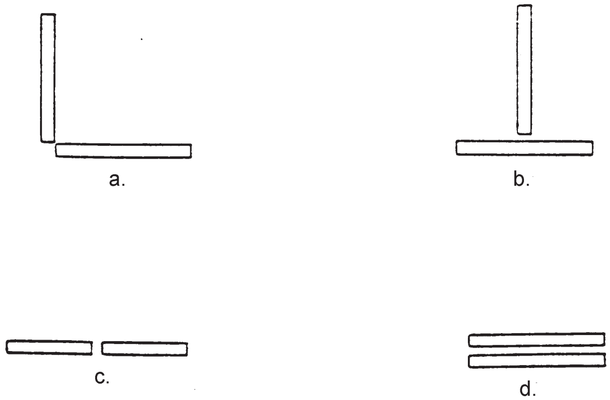


Figure 4-2
TYPES OF JOINTS: A) ANGLE; B) TEE; C) BUTT; D) SURFACE

Although adhesive bonding has benefits in joining dissimilar materials, the application imposes additional design considerations. Using materials with different moduli may result in reduced joint efficiencies. If the materials do not have similar thermal expansion coefficients, temperature changes during elevated temperature cures and in service can increase stresses in adhesive bonds and lower joint strengths (Hart-Smith (1987)). If member materials are not identical, the design should equalize the in-plane and bending stiffnesses and the materials should have similar thermal expansion coefficients.

The identification of possible failure modes is crucial to effective joint design and satisfactory performance. For joints consisting of ductile isotropic materials such as aluminum alloys, four common failure modes are:

1) tensile or buckling failure of the member outside the joint area,
2) shear failure of the adhesive,
3) tensile cracking in the adhesive layer due to tensile or cleavage forces in the joint, and
4) adhesion failure at the adhesive/member interface.

Adhesion failures are least desirable because such interfacial failures typically result in low, inconsistent joint strengths. If the adhesive fails to adhere to the aluminum, this indicates incompatibility of the surface oxide of the aluminum with that particular adhesive. If the aluminum is pretreated and failure occurs at that interface between the pretreatment and the adhesive, this indicates adhesive/pretreatment incompatibility.

The adhesive properties for joint designs may be obtained from mechanical tests. Tensile properties can be obtained using cast adhesive specimens as described in ASTM D 638 (ASTM (2009a)). Adhesive shear properties can be generated using thick adherend tests (Dreiger (1985)) or a torsion test described in ASTM E 229 (ASTM (2009b)). Properties should be obtained for temperatures throughout the range expected in service. Temperature can affect adhesive properties, ductility and toughness, which will affect joint design and performance, including stiffness and failure loads and modes. The adequacy of the design should be checked for the range of service temperatures. Summaries of technology and data are provided by Minford (1993).

For critical applications in complex structures, a complete analysis of the stress components is recommended along with the identification of the potential failure modes. Nonlinear behavior of the adhesive and members should be accounted for in the most effective method of conducting such analysis. Mechanical tests to simulate typical service conditions of adhesive-bonded joints should be performed to verify the predicted failure location and modes.

4.6 Current Adhesive Applications

Adhesives are gaining popularity as a viable structural means of joining aluminum. Today, aluminum adhesive bonding is being used in the transportation, construction, marine, aerospace, and electronic industries. Examples in each category are:

- Transportation: buses, trains, and trailers; automotive seats, hoods, and air bag containers
- Construction: architectural panels
- Marine: boats, ships, and desalination plants
- Aerospace: space vehicles, planes, and helicopters
- Electronics: antennas, computer boards, and cable wires

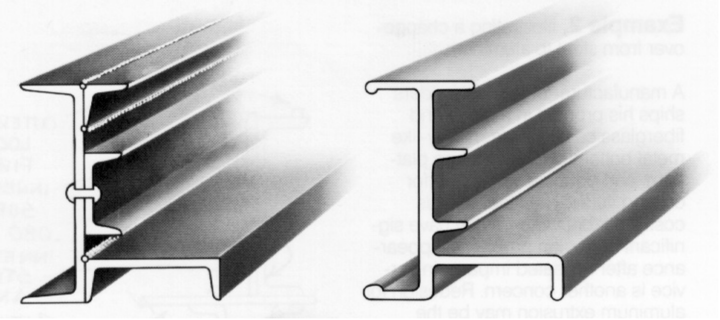
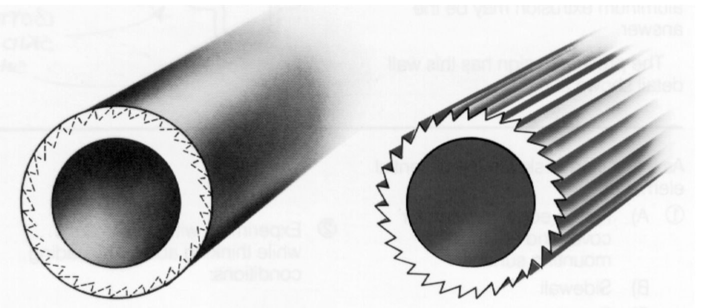
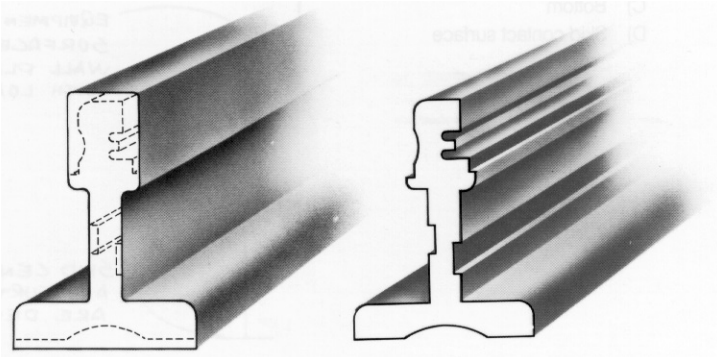
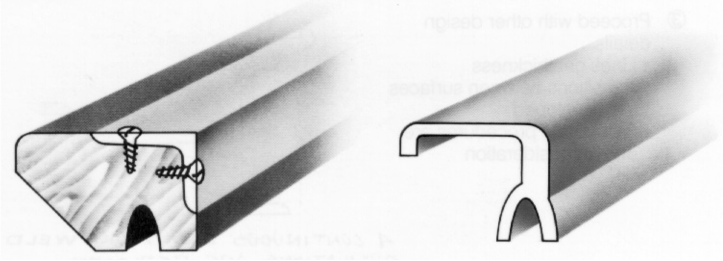
5. Extrusion Design

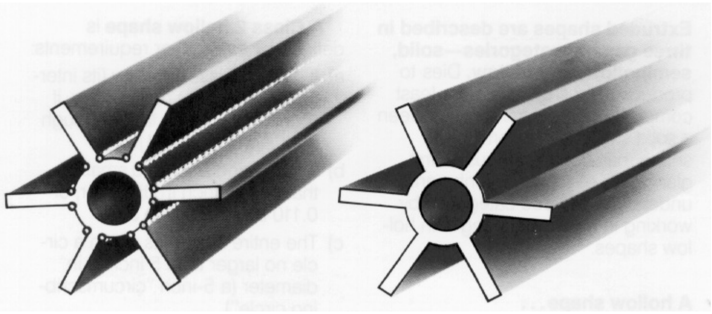
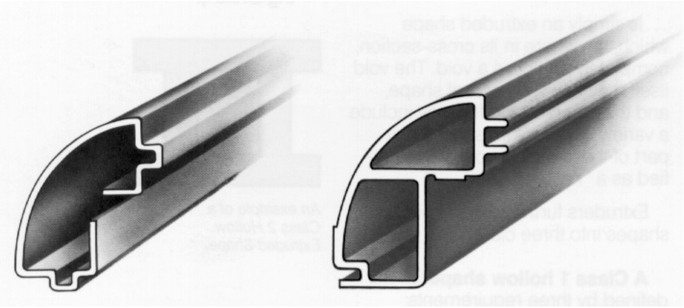
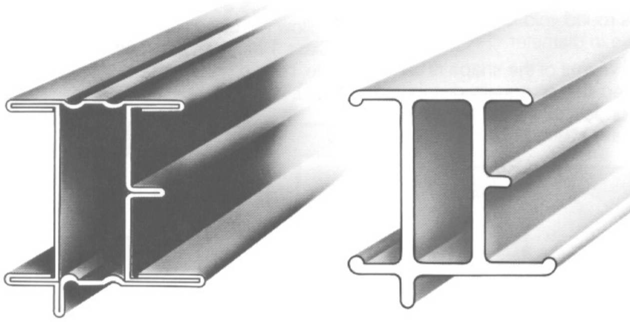
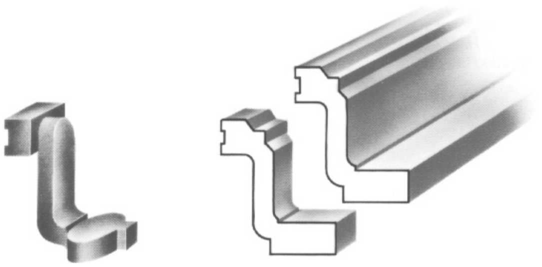
Aluminum can be easily extruded, unlike steel. The extrusion process consists of pushing hot aluminum through a die, likened to pushing tooth paste out of the tube. Custom shapes can be created that place the material where it is most effective.

Cross sections must be constant along their length but they may be intricate. Often fabrication costs can be lowered by consolidating parts or incorporating assembly aids by using extrusions. Extrusions that fit within a circle up to about 30 in. in diameter are possible, but the more common ones fit within a diameter of about18 inches.

The following information in this section is from the *Aluminum Extrusion Manual* (1998).

5.1 Replacing Fabrications with Extrusions

As shown at right, several rolled and riveted structural shapes (left) can be combined into a single aluminum extrusion, thus eliminating all joining costs.	
Machined and stamped sections can be replaced by aluminum sections extruded to exact size and shape.	
As another example, the machining cost and weight of a framing member is reduced by redesigning the member as an extruded section.	
Aluminum extrusions may also replace wood sections. They can be made lighter, stiffer, and stronger, thus eliminating steel reinforcement.	

Welded assemblies are frequently redesigned into extruded sections. Not only is cost reduced, but accuracy and strength are increased.	
Because extrusions permit infinite changes in cross sectional design, they can be produced more readily to meet specific design requirements than rolled sheet sections.	
Crimped tubular sections frequently permit redesign in extruded shapes, with gains in both stiffness and strength. Cost of manufacture is also reduced.	
Small castings, forgings, and parts machined from bar stock may also permit redesign as an extrusion, as long as the cross section is symmetrical in at least one plane.	

5.2 Design Parameters

Five major factors should be considered in the detailed development of an aluminum extrusion design:

- Shape configuration
- Tolerances
- Surface finish
- Alloy
- Circumscribing circle size

These parameters are interrelated in their effect on the extrusion design and its application.

Shape Configuration

The designer's first priority is to satisfy a specific need, and aluminum extrusion allows you to design the shape that best meets your structural and aesthetics requirements. Since extrusion dies are relatively inexpensive, designers can afford to use several different shapes, if that's the best way to achieve their objectives.

Extrusions can be designed to aid in assembly, improve product appearance, reduce or eliminate forming and welding operations, and achieve many other purposes.

Extruded shapes are described in three general categories—solid, semihollow, and hollow. Dies to produce solid shapes are the least complex. The difference between a solid shape and a semihollow shape may not be obvious at first glance. It's easier to describe and understand all three categories by working in reverse, starting with hollow shapes.

A hollow shape is simply an extruded shape which, anywhere in its cross section, completely encloses a void. The void itself may have any sort of shape, and the complete profile may include a variety of other forms; but if any part of it encloses a void, it's classified as a "hollow."

Tube and Pipe are specific forms of hollow shapes.

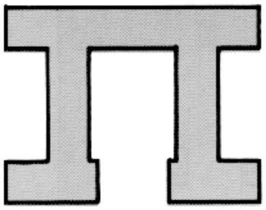
"Tube" is a hollow section that is long in comparison to its cross-sectional size. It is symmetrical and has uniform wall thickness except as affected by corners. It may be round or elliptical, or square, rectangular, hexagonal, or octagonal. "Extruded tube," as the name indicates, is tube produced by hot extrusion; "drawn tube" is produced by drawing through a die.

"Pipe" is a tube with certain standardized combinations of outside diameter and wall thickness. These are commonly designated by "Nominal Pipe Sizes" and by "ANSI (American National Standards Institute) Schedule Numbers."

A semihollow shape is one that partially encloses a void—for example, a circle or rectangle with a gap in one side; but a solid shape can also partially enclose a void, and the difference may not be obvious. It is defined mathematically, by comparing the area of the partially enclosed void to the size of the gap (actually, to the mathematical square of the gap size). If that ratio is larger than a certain number, the shape is classified as semihollow; if the ratio is smaller, the shape is considered a solid.

The dies required to make semihollow shapes are moderately more expensive than solid shape dies, and the output of those dies tends to approach tolerance limits. Tooling life and productivity are both improved with decreasing ratios, thus reducing cost.

A solid extruded shape is any shape that is not a hollow or a semihollow. This covers a wide range including, for example, compact cross-sections with or without projections; angular or curved shapes; and those wrap-around shapes whose void area/gap^2 ratios are too low for the semihollow-class.



Example of a solid shape

Figure 5-1

Extruded rod is a solid shape with a round cross-section at least 0.375 in. in diameter.

Extruded bar is a solid shape whose cross-section is square, rectangular, hexagonal or octagonal, and whose width between parallel faces is a least 0.375 inches.

If the dimension across any of these rod- or bar-type shapes is less than 0.375 in., it is classified as wire.

Tolerances

In many applications in which the extrusion will be part of an assembly of components, tolerances are critical. A designer should be aware of the standard dimensional tolerances to which extrusions are commercially produced. These tolerances generally cover such characteristics as straightness, flatness, and twist, and such cross-sectional dimensions as thickness, angles, contours and corner or fillet radii. Both standard and precision tolerances for extrusions are given in *Aluminum Standards and Data,* Section 11.

Aluminum extrusions are often designed to minimize or eliminate the need for machining. If desired, many extrusions can be produced to the recently introduced "precision tolerances" or to closer-than-standard custom tolerances, generating cost savings in secondary operations; such savings may range from modest to very large, depending on circumstances. The designer should consider his requirements carefully and order special tolerances only where they are really needed.

If extruded parts are to interlock in any manner, the designer should work with the supplier to make sure that tolerances will provide a proper fit.

Surface Finish

One advantage of aluminum extrusions is the variety of ways the surface can be finished, and this offers another range of choices to the designer.

As-extruded, or “mill,” finish can range from “structural,” on which minor surface imperfections are acceptable, to “architectural,” presenting uniformly good appearance. It should be understood that under normal circumstances aluminum may be marred because it is a relatively soft metal and that special care is required if a blemish free surface is desired.

Other finishes include scratch finishing, satin finishing and buffing. Aluminum can also be finished by clear or colored anodizing, or by painting or other coatings.

If a product will have surfaces that are exposed in use, where normal processing marks may be objectionable, the extruders should be told which surfaces are critical. They can design a die that orients the shape to protect those surfaces during the extrusion process; they can also select packaging that will protect the product during shipment.

Alloy Selection

Aluminum extrusions are made in a wide variety of alloys and tempers to meet a broad spectrum of needs. Selection is made to meet the specific requirements in strength, weldability, forming characteristics, finish, corrosion resistance, machinability, and sometimes other properties.

The complete list of registered aluminum alloys is quite long, but in practice a few alloys are chosen repeatedly for extrusion because of their versatility and highly suitable characteristics. Extruders generally stock the three or four most frequently used alloys. When their specialized markets justify it, individual companies include in their inventories additional alloys that will vary with the needs of their major customers. Thus, a substantial variety of extrusion alloy/temper products is regularly available.

The 6xxx-series of aluminum alloys is selected for nearly 75 percent of extrusion applications. Of those, alloys 6063 and 6061 are used most frequently.

Alloy 6063 is used for a broad range of solid and hollow products. It is easily welded, and it has a pleasing natural finish and excellent corrosion resistance. 6063 is used in architecture and in many moderate-stress applications.

Alloy 6061 is a good all-purpose extrusion alloy, combining high mechanical properties with good corrosion resistance, weldability and machining characteristics. Alloy 6061 is used in many structural applications.

Many other alloys are used for extrusions to meet particular requirements. To mention a few:

Characteristics	Alloys
High strength	6066, 6070, 6082, 7005
High corrosion resistance	1100, 3003
High electrical conductivity	6101

The designer should consult alloy and temper tables and discuss specific needs with the extrusion supplier.

Circumscribing Circle Size

One measurement of the size of an extrusion is the diameter of the smallest circle that will entirely enclose its cross-section—its “circumscribing circle.” This dimension is one factor in the economics of an extrusion. In general, extrusions are most economical when they fit within medium-sized circumscribing circles: that is, one with a diameter between 1 and 10 inches.

The example shown in Figure 5-2 would be classified as a 3 to 4 in. circle size shape.

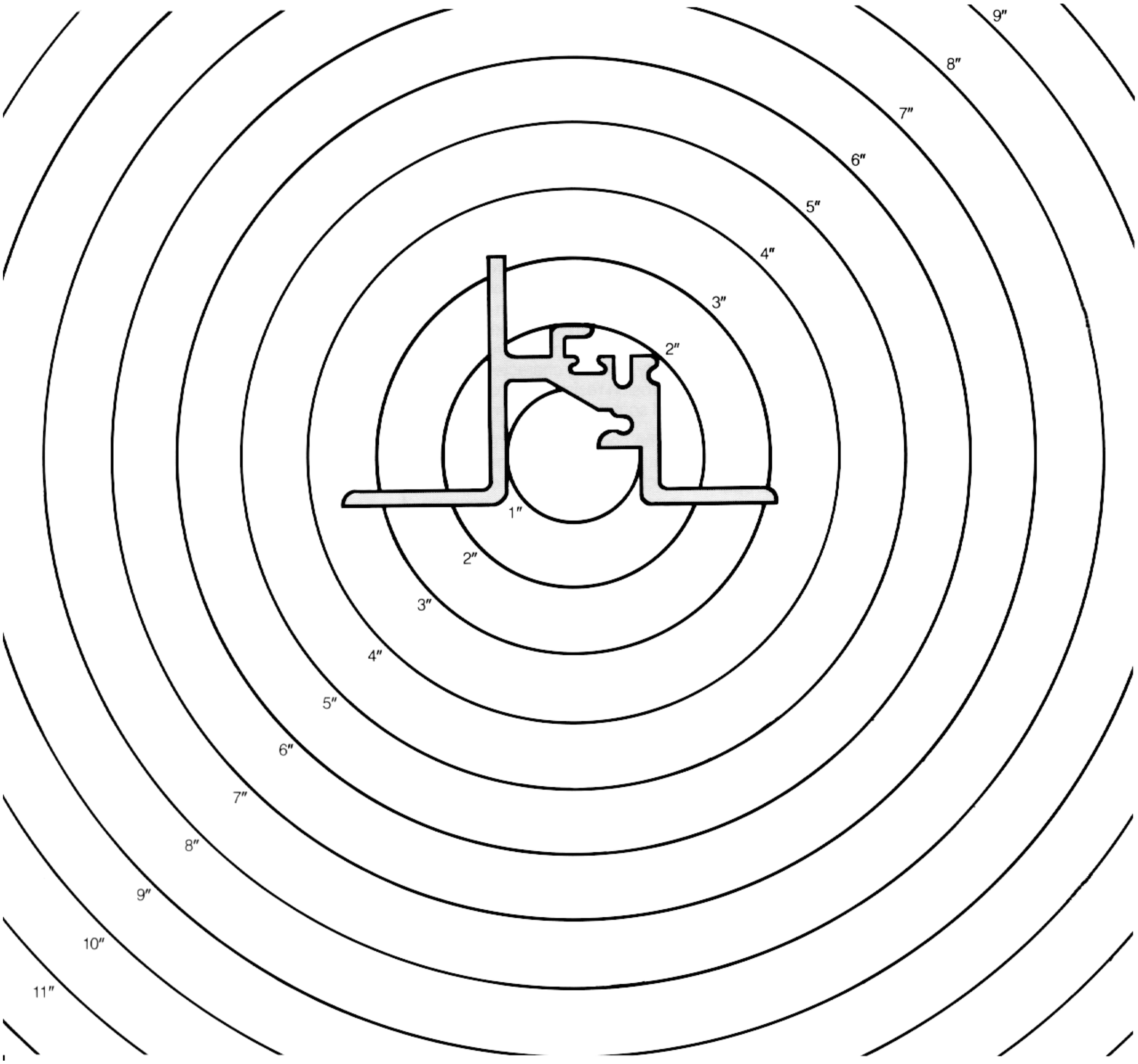


Figure 5-2

5.3 Design Guidelines

Good Extrusion Design Practices

At this stage in the development of an extruded product, the designer has determined its functional shape and size, and considered appropriate tolerances, surface finishes and alloys.

Before proceeding, it makes sense to review the extruder's available standard shapes. It may be possible to adapt a standard shape to the needs of the product, with little or no modification.

If a standard shape is not readily adaptable, the design can be completed as a custom shape perfectly suited to the requirements of the product.

Here are a few tips on good practices in custom-designing aluminum extrusions:

Specify the Most Appropriate Metal Thicknesses

Specify metal thicknesses that are just heavy enough to meet your structural requirements. Even in low stress areas, however, keep sufficient thickness to avoid risking distortion or damage. Some shapes tend to invite distortion during the extrusion process (such as an asymmetric profile or thin details at the end of a long flange). Such tendencies exert more influence on thin-walled shapes than on those with normal metal thickness.

Keep Metal Thickness as Uniform As Possible

Extrusion allows you to put extra metal where it is needed—in high-stress areas, for example—and still save material by using normal dimensions elsewhere in the same piece. Adjacent wall thickness ratios of less than 2-to-1 are extruded without difficulty. However, large contrasts between thick and thin areas may create uneven conditions during extrusion. It is best to maintain near uniform metal thickness throughout a shape if possible. When a design combines thick and thin dimensions, streamline the transitions with a radius (a curve, rather than a sharp angle) at junctions where the thickness changes sharply. Rounded corners ease the flow of metal.

Visualize the Die and the Metal Flow

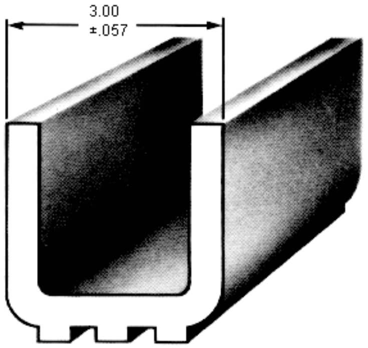
Remember what an extrusion die does: while it lets metal flow through its shaped aperture, it must hold back metal all around that aperture against great force. When you design a shape for extrusion, you are simultaneously designing a die aperture and you must take extrusion forces and metal flow into account.

For example, a U-shaped channel in an extrusion corresponds to a solid "tongue" in the die, attached at only one end. Flexibility in this tongue can alter the aperture slightly under the pressure of extrusion; the deeper you make the channel, the longer you make the tongue and the more difficult it becomes to regulate the extruded dimensions. On the other hand, rounding corners at the base and tip of the tongue can ease metal flow and so help to keep the extruded dimensions more uniform. Even corners rounded to only 1⁄64 in. radius can facilitate extruding.

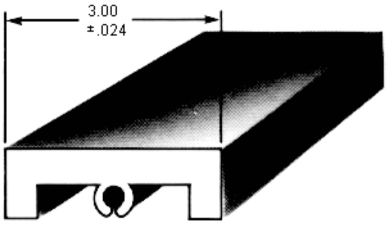
Visualize the shape of the die that must produce your design, and try to minimize shapes that would weaken the die or impede metal flow.

Use Metal Dimensions for Best Tolerance

Dimensions measured across solid metal are easier to produce to closer tolerances than those measured across a gap or angle (see Figure 5-3). So rely on metal dimensions as much as possible when designing close-fitted mating parts or other shapes requiring closer tolerances. Standard industry dimensional tolerances are entirely adequate for many applications, but special tolerances can be specified if necessary.



An Open Space Dimension is more difficult to hold to close tolerances.



A Metal Dimension can be extruded to close tolerances.

Figure 5-3

Smooth All Transitions

Transitions should be streamlined by a generous radius at any thick-thin junction.

Keep Wall Thickness Uniform

The preceding shape can be *further improved* by maintaining uniform wall thickness.

In addition to using more metal, thick-thin junctions give rise to distortion, die breakage or surface defects on the extrusion.

Ribs Help Straightening Operation

Wide, thin sections can be hard to straighten after extrusion. Ribs help to reduce twisting and to improve flatness.

Symmetry Preferred in Semi-Hollow Areas

When designing, visualize the die and tongue that will be necessary to produce a semi-hollow shape. By keeping the void symmetrical you lessen the chances that the die tongue may break.

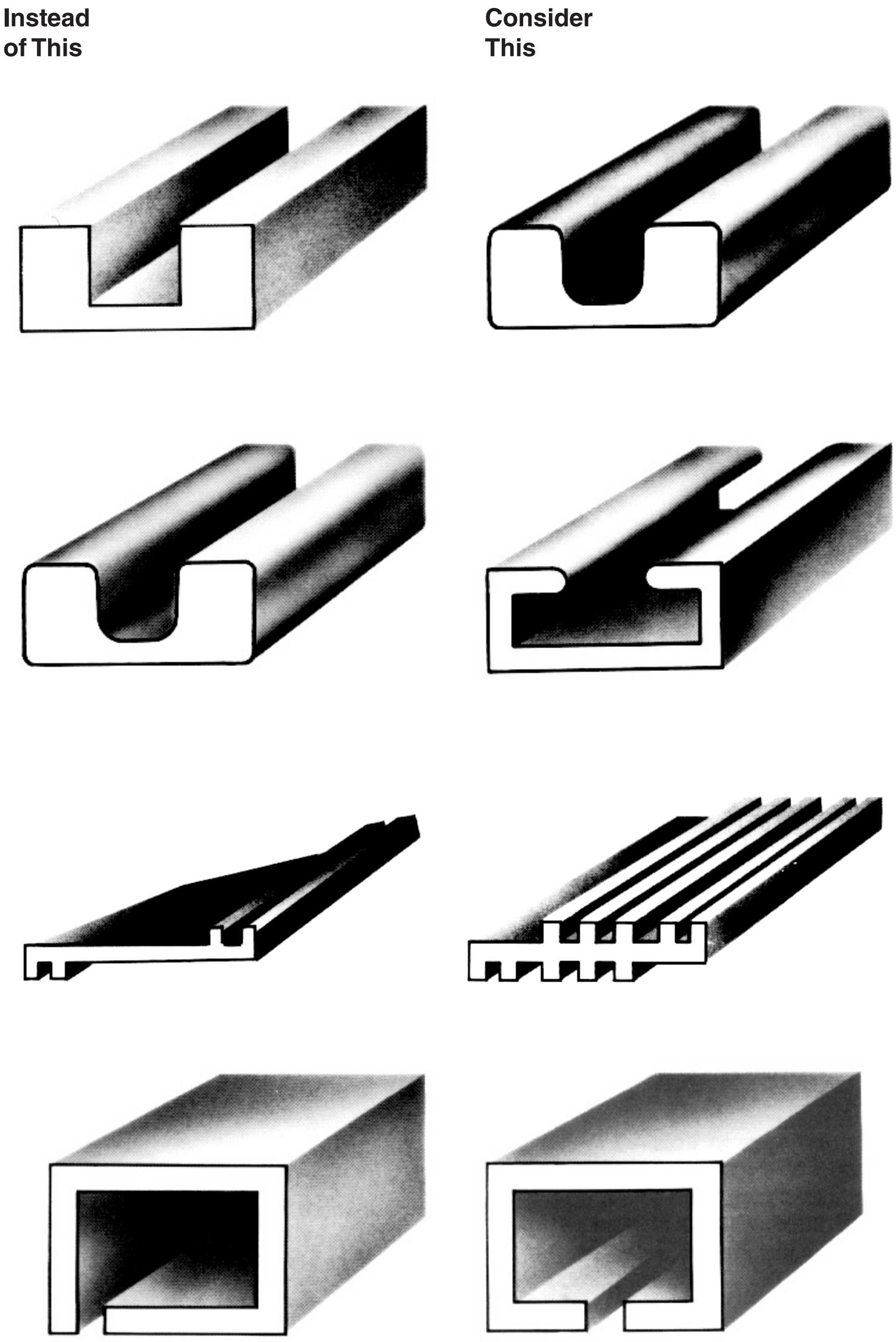


Figure 5-4

5.4 Design for Assembly

Aluminum extrusions can be designed for joining by a wide variety of assembly methods such as riveting, bolting, welding, brazing, soldering and adhesive bonding.

They can also be designed to fit, hook or snap together with mating parts. Hinges or slides can often by “designed-in” as integral parts of extrusions, eliminating the need for additional assembly and moving parts.

Four types of extruded joints are discussed in this section:

- Nesting Joints
- Interlocking Joints
- Snap-Fit Joints
- Screw Slots

Nesting Joints

Nesting joints, which include lap joints and tongue-and-groove joints, have mating elements that are shaped to be assembled with little or no self-locking action.

They serve primarily to align adjoining parts, and they usually depend on rivets, bolts, adhesives, confinement within a rigid frame, or other fasteners to hold them together.

Lap joints, shown in Figure 5-5, are the simplest nesting joints.

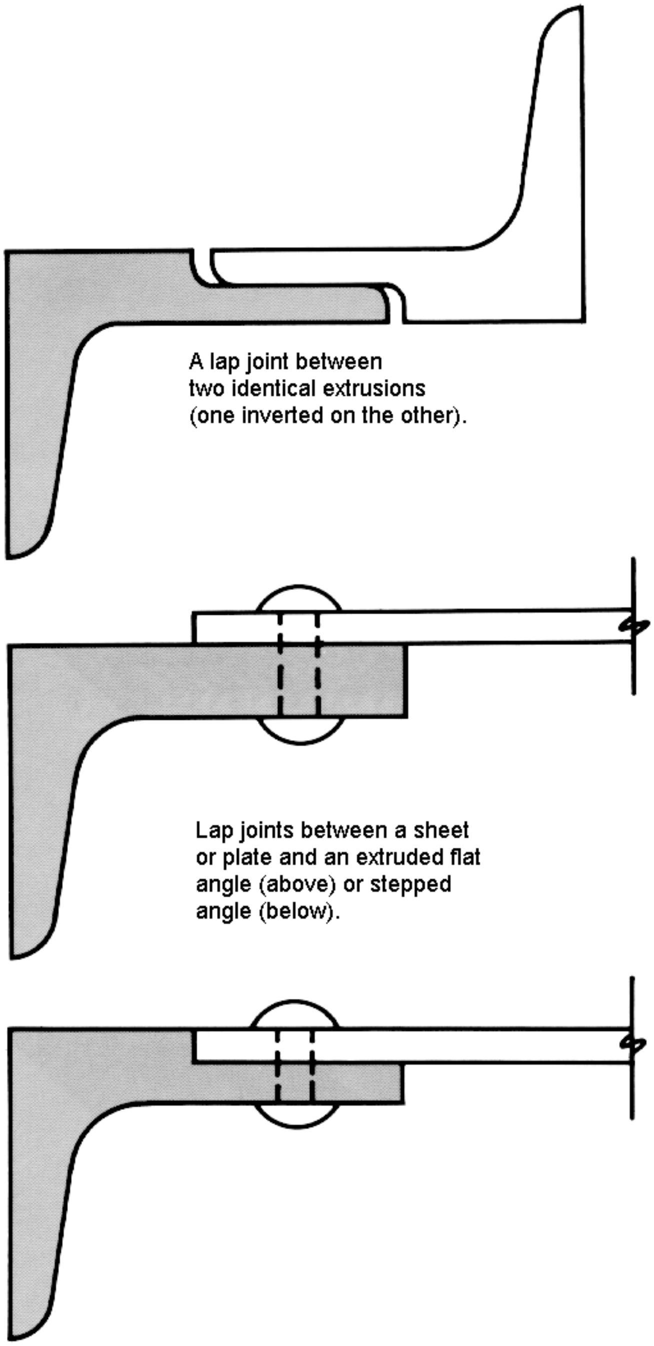
Interlocking Joints

The interlocking joint is, in effect, a modified tongue-and-groove. But instead of being straight, the two mating elements are curved and so cannot be assembled or (more to the point) disassembled by simple straight-line motion. They are assembled by a rotating motion and will not separate without a corresponding counter-rotation. As long as the parts are held in their assembled position, they strongly resist separation and misalignment in both the horizontal and the vertical directions.

The amount of rotation required for interlocking assembly depends on the geometry of the design. It can be made more or less than 45°, as long as the design allows enough clearance for the required rotation.

Interlocking joints can be secured in at least five ways, all based on preventing counter-rotation.

- Fastening the elements to structural cross-members.
- Restraining the assembly within a rigid frame.
- Restraining the assembly with channel end-closures.
- Fastening the joint with rivets, welds, adhesives or other devices.
- Providing a folding, locking flange as shown in Figure 5-6.



A lap joint between two identical extrusions (one inverted on the other).

Lap joints between a sheet or plate and an extruded flat angle (above) or stepped angle (below).

Figure 5-5

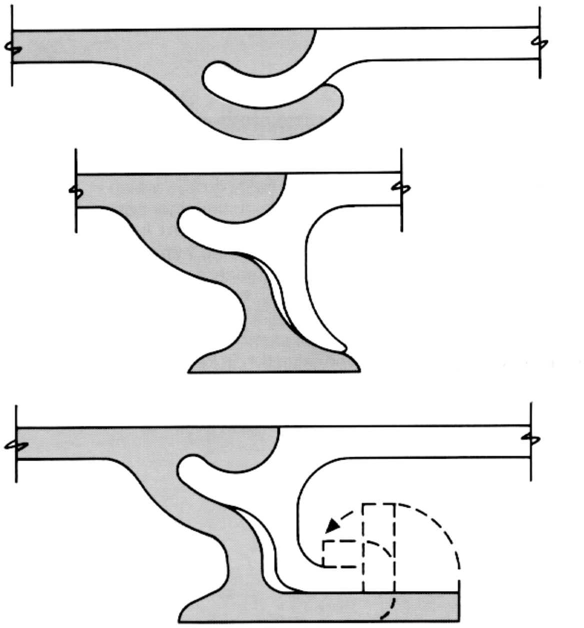
Snap-Fit Joints

A "snap-fit" or "snap-lock" joint (see Figure 5-7) is one which is self-locking and requires no additional fasteners to hold the joint together.

The mating parts of a snap-fit joint exert a cam action on each other, flexing until one part slips past a raised lip on the other part. Once past this lip, the flexed parts snap back to their normal shape and the lip prevents them from separating. After it is snapped together, this joint cannot be disassembled unintentionally.

This joint's strength can be increased by applying adhesive to the mating surfaces before assembly. Even short lengths of an adhesively bonded, snap-fit joint cannot be easily slid apart.

Precise dimensions are critical in a snap-fit joint. Experienced extrusion designers who are fully conversant with snap-fit production requirements can determine the precise final dimensions.



Interlocking joint with a folding, locking flange which prevents counter-rotation and disassembly.

Figure 5-6

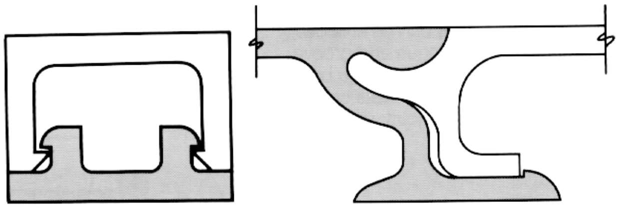


Figure 5-7

Screw Slots

Screw slots are often used to facilitate the assembly of aluminum extrusions. Standard screw slots are illustrated in Figure 5-8 and should always be used with self tapping screws.

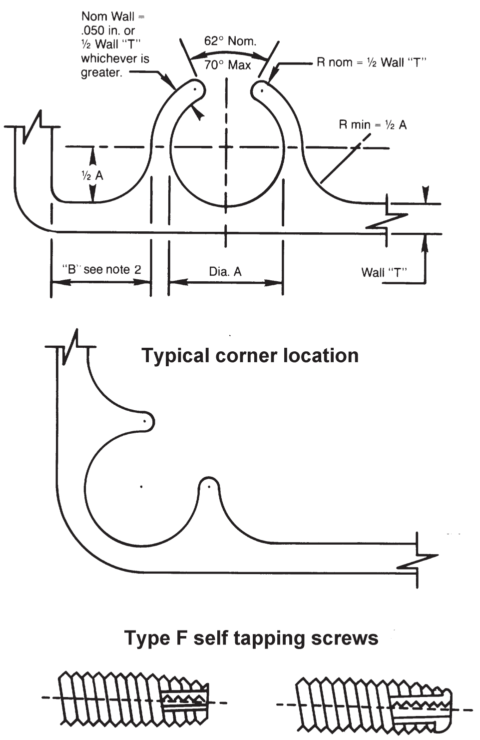
The screw slot should be designed so that the area of the void and the metal thickness surrounding it is symmetrical about the center line of the gap.

Sheet metal type screws are not recommended since their thread projects to the end of the screw and thereby can "walk" through the slot opening.

Typical location away from corner

Typical corner location

Type F self tapping screws



Self Tapping Screw Type F		Screw OD (in.)	A DIA. (in.)
NC	NF		
4–40[1]	4–48[1]	0.120	0.099 ± 0.006
6–32[1]	6–40[1]	0.138	0.120 ± 0.006
8–32	8–36	0.164	0.147 ± 0.007
10–24	10–32	0.190	0.169 ± 0.007
12–24	12–28	0.216	0.190 ± 0.007
¼ x 20	¼ x 28	0.250	0.228 ± 0.007

[1] Not recommended for incorporation on inside wall of hollow or semihollow shapes.

[2] The recommended location for screw slots on the inside of hollow or semihollow shapes is at the corners. When not located at corners dimension "B" must be at least 0.250 in.

Figure 5-8

6. Preventing Corrosion

A great deal of technology and experience exists for successful prevention of corrosion in assemblies and structures. The following information has been adapted from Hatch (1984).

Proper selection/application of the following measures can be used to prevent aluminum corrosion:

- Alloy and temper selection
- Design
- Joints
- Inhibitors
- Protective coatings
- Cathodic protection

Alloy and temper selection: Alloys of the 1xxx, 3xxx, 5xxx, and 6xxx series generally have very good corrosion resistance in natural environments and can often be used without corrosion protection. Temper selection for the 1xxx, 3xxx, and 6xxx series alloys and for the 5xxx series alloys containing up to 3% magnesium (e.g. 5005, 5050, 5052, and 5454) may be based on factors other than corrosion. For 5xxx series sheet and plate alloys containing more than 3% magnesium (e.g. 5083, 5086, and 5456) for applications with service temperatures exceeding 150°F or in marine environments, the temper should be limited to H116 or H321 and material should comply with ASTM B 928 to guard against intergranular and exfoliation corrosion.

Alloys of the 2xxx and 7xxx series alloys have relatively poor corrosion resistance and require corrosion protection. Temper selection for the 2xxx and 7xxx series alloys can significantly affect exfoliation and stress corrosion resistance. For these alloys, consideration should also be given to stress corrosion cracking (SCC). SCC can occur when residual or assembly stresses occur in the through-thickness or short transverse direction. This can be minimized by considering temper selection, residual stresses from fabrication (e.g. forming, machining, and thermal treatments), and fit up details.

Design: Factors that may affect corrosion resistance can be more cost-effectively considered during the design phase rather than after the design is finalized:

- Avoid contacts with dissimilar metals (galvanic corrosion prevention discussed below).
- Avoid crevices, especially at joints (crevice corrosion prevention discussed below).
- Avoid skip welding by using continuous welding.
- Avoid standing fluid and poultice catchments.
- Avoid placing absorbent materials, such as open-cell gaskets, insulation, and soundproofing, against aluminum.
- Avoid direct impingement by fluid streams, especially sharp pipe bends.
- Avoid heat transfer hot spots.
- Avoid corrosive conditions when locating parts and joints.
- Avoid sharp edges when coating will be used.

Joints: A key area for corrosion prevention is joints. Joints may involve aluminum and other metals. Galvanic corrosion can occur when aluminum is joined to other metals and the joint is connected by a conductive fluid. Joints designed so that they remain dry in service or where the dissimilar metals are not electrically connected, even by a remote path, will be free from galvanic corrosion. A common tool for predicting which metal will corrode (anode) in a given couple is the galvanic series, which is environment-specific (see Table 6-1 for an example in sodium chloride solution). In Table 6-1 the metal in a galvanic couple that is toward the *active* end of the galvanic series will corrode, and the other metal in the couple which is toward the *noble* end of the series will not corrode. The galvanic series is useful only as a predictive tool as to location of corrosion in a galvanic couple, not corrosion rate. However, selection of couple members that are close together in the galvanic series minimizes galvanic corrosion. Aluminum can be coupled to magnesium, zinc, cadmium, and passive stainless steel in most environments without galvanic corrosion. In most other galvanic couples aluminum will experience galvanic corrosion.

Where dissimilar metals must be joined, creating an undesirable galvanic couple, several steps can be taken to minimize corrosion. The exposed area of the more noble or cathodic metal should be minimized by design and by application of protective coatings (e.g. paint, gasket, or tape). At bolted or riveted galvanic joints (e.g. aluminum to steel) the fasteners (the smaller exposed surface area) should be the more noble material, such as steel or 3xx series stainless steel rather than aluminum. If using steel fasteners, a further required step is to coat the fasteners with a zinc (galvanizing) or other suitable coating.

Where galvanic couples have only a few points of electrical contact, it may be possible to control corrosion by electrical insulation. Insulation can be effective only when all points of electrical contact are broken. Insulation can be achieved by inserting nonmetallic, non-wicking bushings, gaskets, sleeves, or tapes into joints. Such insulation is difficult to achieve in large, complex structures where remote electrical paths may exist.

Crevices are inevitable in structures. When crevices trap foreign matter, accelerated corrosion may result. Often joints can be located or oriented to minimize moisture ingress and retention. Adhesives, sealants, and nonabsorbent gaskets can prevent the ingress of moisture into crevices. Continuous welds are more desirable than intermittent welds because they leave no crevices. A type of crevice corrosion known as poultice corrosion can occur under foreign materials, such as mud, paper, or cloth. Poultice corrosion can often be minimized by avoiding catchments and pockets during design of a structure.

Inhibitors: In fluid-carrying systems where piping of aluminum and other metals are joined, a thick-walled, replaceable aluminum nipple should be used at the joint. In closed

Table 6-1
GALVANIC SERIES IN SODIUM CHLORIDE SOLUTION (similar to sea water)

Magnesium	Anode
Zinc	
Aluminum alloy 7072 (used in Alclad products)	
5xxx aluminum alloys	
7xxx structural aluminum alloys	
1xxx, 3xxx, 6xxx aluminum alloys	
Cadmium	
2xxx aluminum alloys	
Iron and steel	
Lead	
Tin	
Brass	
Copper	
Stainless steel (3xx, passive)	
Nickel	Cathode

loop, mixed metal fluid-carrying systems, such as automotive cooling systems, it may be possible to control galvanic corrosion with a mixed metal corrosion inhibitor. Mixed metal fluid-carrying systems that include aluminum and cannot be treated with inhibitors should not contain copper.

Protective Coatings: When surface treatments such as anodizing, organic coating, or plating are used on aluminum to provide consistent appearance or improve corrosion resistance, the quality of the treatment is extremely important. If flaws or points of damage occur which expose the substrate aluminum surface, accelerated localized pitting corrosion may result. See Part I and Part II Section M.7 for additional information on contact with dissimilar materials.

Cathodic Protection: For aluminum structures that are buried or immersed in aqueous environments, corrosion may be controlled by application of the electrochemical process known as cathodic protection.

7. Fire Protection

Aluminum alloys are non-combustible when tested in accordance with ASTM E 136. The behavior of aluminum and steel members exposed to fire are compared below.

1. Both aluminum and steel members are noncombustible.
2. The cross sectional areas of aluminum members are usually about 40% larger than those of steel.
3. The thermal conductivity of aluminum is about 2.7 times that of steel.
4. Aluminum's strength degrades at much lower temperatures than that of steel.

These issues affect the relative performance of the two materials in a fire. Aluminum parts exposed to fire would be expected to reach a lower temperature than steel, but aluminum's strength relative to that at room temperature is more degraded compared to that for steel. Aluminum members thus need more insulation than steel members to resist the effects of fire.

Kaufman and Kasser (1963) tested fire protection for aluminum members. The criteria for establishing the fire protection for aluminum were:

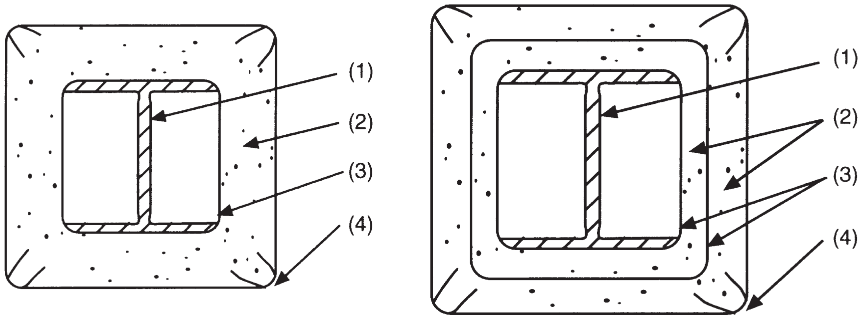
1. To ensure that strength during a fire will at least equal the allowable stresses at room temperature, the aluminum temperature should be limited to 500°F.
2. To ensure that there will be no substantial change in properties after a fire, the aluminum temperature should be limited to 375°F.

Light weight vermiculite plaster was used in the tests, and specimens were as indicated on Figure 7-1. The relative thicknesses of protection required for various periods of time are shown below.

Part I Appendix 4 and Eurocode 9, Part 1-2 address aluminum structural design for fire conditions.

RELATIVE THICKNESS OF VERMICULITE
REQUIRED FOR FIRE PROTECTION OF STRUCTURAL ALUMINUM MEMBERS

Fire Protection Period (hours)	Ratio of Aluminum Member's Insulation Thickness to Steel Member's Insulation Thickness
1	1.7
2	1.9
3	1.8
4	1.7



COLUMN 1
2-in. nominal

COLUMN 2
3-in. nominal

Numbers designate materials as follows:
(1) 8WF × 10.72 column
(2) Vermiculite plaster
(3) Lath
(4) Keystone key corner beads

Figure 7-1
SPECIMENS FOR FIRE PROTECTION TESTS

8. Sustainability

8.1 Reflectance and Emittance

In warm climates, the more roofs reflect and radiate the sun's radiation, the more energy they save by reducing buildings' cooling requirements. Solar reflectance, also called albedo, measures a material's ability to reflect sunlight—including visible, infrared, and ultraviolet wavelengths—on a scale of 0 to 1 and can be expressed as a decimal fraction or a percentage. Thermal emittance is the fraction of energy a material radiates away after it is absorbed. Emittance is the ability to release absorbed heat and is also expressed as a decimal fraction or a percentage.

Reflectance is determined using ASTM E 1918 or C 1549; emittance is determined according to ASTM E 408 or C 1371.

Cooling energy requirements are significantly reduced by roofing materials with high reflectance and emittance. For prepainted metal roofing, the substrate has little or no influence on the exterior surface reflectance and emittance. The emittance of painted metal is about 0.8 to 0.9. The reflectance is a function of paint color and type.

Reflectance and emittance of bare aluminum is affected by surface roughness, oxides, and cleanliness. Typical total solar reflectance is 0.6 to 0.8. Mill finish aluminum can have very low emittance (0.02 to 0.10), although this increases slightly as natural oxides form. Aluminum is often anodized to create a durable layer of aluminum oxide that is much thicker than that which occurs naturally. Anodized aluminum has significantly higher emittance (0.6 to 0.9).

8.2 Recycling

Aluminum can be recycled indefinitely without loss of properties. Aluminum is 100% recyclable, and recycling aluminum saves approximately 95% of the energy required to produce aluminum from bauxite. Using recycled aluminum instead of raw materials reduces air and water pollution by about 95%.

A 2008 survey of aluminum producers indicated that the total recycled content of domestically produced flat rolled products for the building and construction market was approximately 85%. On average, 60% of the total product content was from post-consumer sources. To determine the recycled content of specific aluminum products, consult the supplier.

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Aluminum Design Manual

PART IV

Material Properties

IV
Material Properties

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Information in Part IV is excerpted from *Aluminum Standards and Data 2009* and *Aluminum Standards and Data 2009 Metric SI*.

1. General Characteristics of Aluminum

A unique combination of properties makes aluminum one of our most versatile engineering and construction materials. A mere recital of its characteristics is impressive. It is light in mass, yet some of its alloys have strengths greater than that of structural steel. It has high resistance to corrosion under the majority of service conditions, and no colored salts are formed to stain adjacent surfaces or discolor products with which it comes into contact, such as fabrics in the textile industry and solutions in chemical equipment. It has no toxic reaction. It has good electrical and thermal conductivities and high reflectivity to both heat and light. The metal can easily be worked into any form and readily accepts a wide variety of surface finishes.

Lightness is one of aluminum's most useful characteristics. The specific gravity is about 2.7. The mass ("weight") of aluminum is roughly 35 percent that of iron and 30 percent that of copper.

Commercially pure aluminum has a tensile strength of about 13,000 pounds per square inch. Thus its usefulness as a structural material in this form is somewhat limited. By working the metal, as by cold rolling, its strength can be approximately doubled. Much larger increases in strength can be obtained by alloying aluminum with small percentages of one or more other elements such as manganese, silicon, copper, magnesium or zinc. Like pure aluminum, the alloys are also made stronger by cold working. Some of the alloys are further strengthened and hardened by heat treatments so that today aluminum alloys having tensile strengths approaching 100,000 pounds per square inch are available.

A wide variety of mechanical characteristics, or tempers, is available in aluminum alloys through various combinations of cold work and heat treatment. In specifying the temper for any given product, the fabricating process and the amount of cold work to which it will subject the metal should be kept in mind. In other words, the temper specified should be such that the amount of cold work the metal will receive during fabrication will develop the desired characteristics in the finished products.

Aluminum and its alloys lose part of their strength at elevated temperatures, although some alloys retain good strength at temperatures from 400˚F to 500˚F. At subzero temperatures, however, their strength increases without loss of ductility, so that aluminum is a particularly useful metal for low-temperature applications.

When aluminum surfaces are exposed to the atmosphere, a thin invisible oxide skin forms immediately, which protects the metal from further oxidation. This self-protecting characteristic gives aluminum its high resistance to corrosion. Unless exposed to some substance or condition that destroys this protective oxide coating, the metal remains fully protected against corrosion. Aluminum is highly resistant to weathering, even in industrial atmospheres that often corrode other metals. It is also corrosion resistant to many acids. Alkalis are among the few substances that attack the oxide skin and therefore are corrosive to aluminum. Although the metal can safely be used in the presence of certain mild alkalis with the aid of inhibitors, in general, direct contact with alkaline substances should be avoided.

Some alloys are less resistant to corrosion than others, particularly certain high-strength alloys. Such alloys in some forms can be effectively protected from the majority of corrosive influences, however, by cladding the exposed surface or surfaces with a thin layer of either pure aluminum or one of the more highly corrosion-resistant alloys.

A word of caution should be mentioned in connection with the corrosion-resistant characteristics of aluminum. Direct contacts with certain other metals should be avoided in the presence of an electrolyte; otherwise galvanic corrosion of the aluminum may take place in the vicinity of the contact area. Where other metals must be fastened to aluminum, the use of a bituminous paint coating or insulating tape is recommended.

The fact that aluminum is nontoxic was discovered in the early days of the industry. It is this characteristic that permits the metal to be used in cooking utensils without any harmful effect on the body, and today we find also a great deal of aluminum equipment in use by food processing industries. The same characteristic permits aluminum foil wrapping to be used safely in direct contact with food products.

Aluminum is one of the two common metals having an electrical conductivity high enough for use as an electric conductor. The conductivity of electric conductor grade (1350) is about 62 percent that of the International Annealed Copper Standard. Because aluminum has less than one-third the specific gravity of copper, however, a pound of aluminum will go about twice as far as a pound of copper when used for this purpose. Alloying lowers the conductivity somewhat, so that wherever possible alloy 1350 is used in electric conductor applications.

The high thermal conductivity of aluminum came prominently into play in the very first large-scale commercial application of the metal in cooking utensils. This characteristic is important wherever the transfer of thermal energy from one medium to another is involved, either heating or cooling. Thus aluminum heat exchangers are commonly used in the food, chemical, petroleum, aircraft and other industries. Aluminum is also an excellent reflector of radiant energy through the entire range of wavelengths, from ultraviolet, through the visible spectrum to infrared and heat waves, as well as electromagnetic waves of radio and radar.

Aluminum has a light reflectivity of over 80 percent, which has led to its wide use in lighting fixtures. Aluminum roofing reflects a high percentage of the sun's heat, so that buildings roofed with this material are cooler in summer.

The ease with which aluminum may be fabricated into any form is one of its most important assets. Often it can compete successfully with cheaper materials having a lower degree of workability. The metal can be cast by any method known to foundrymen; it can be rolled to any desired thickness down to foil thinner than paper; aluminum sheet can be stamped, drawn, spun or roll-formed. The metal also may be hammered or forged. Aluminum wire, drawn from rolled rod, may be stranded into cable of any desired size and type. There is almost no limit to the different profiles (shapes) in which the metal may be extruded.

The ease and speed with which aluminum may be machined is one of the important factors contributing to the low cost of finished aluminum parts. The metal may be turned, milled, bored, or machined in other manners at the maximum speeds of which the majority of machines are capable. Another advantage of its flexible machining characteristics is that aluminum rod and bar may readily be employed in the highspeed manufacture of parts by automatic screw machines.

Almost any method of joining is applicable to aluminum: riveting, welding, brazing or soldering. A wide variety of mechanical aluminum fasteners simplifies the assembly of many products. Adhesive bonding of aluminum parts is widely employed, particularly in joining aircraft components.

For the majority of applications, aluminum needs no protective coating. Mechanical finishes such as polishing, sand blasting or wire brushing meet the majority of needs. In many instances, the surface finish supplied is entirely adequate without further finishing. Where the plain aluminum surface does not suffice, or where additional protection is required, any of a wide variety of surface finishes may be applied. Chemical, electrochemical and paint finishes are all used. Many colors are available in both chemical and electrochemical finishes. If paint, lacquer or enamel is used, any color possible with these finishes may be applied. Vitreous enamels have been developed for aluminum, and the metal may also be electroplated.

Aluminum sheet, because of its superior corrosion resistance and smooth continuous surface, is an excellent base for the high quality paints used in producing painted sheet. The chemical pretreatment plus the application of high quality thermally cured paint assures a finish that will exhibit no cracking, blistering, or peeling. Accidental damage to products made of painted aluminum sheet will not result in unsightly rust areas or streaks. Experience has shown that paint in the quality used for this product, properly formulated, applied and cured, will show little change in color or loss of gloss after one year's service in the adverse climatic conditions of south-central Florida.

Highly industrialized areas may cause some color change due to atmospheric contaminants.

Proper maintenance can extend the service life considerably—even the finest automobiles require occasional washing and polishing if they are to retain their original appearance.

Even after many years of service most advantages of the painted sheet remain. It can be repainted with any good grade of house paint with no danger of cracking or peeling, such as is often experienced when paint is applied to other types of base materials.

Painted sheet and the products made from it should be handled with care to avoid damage to the paint film. Repair of large damaged areas is not recommended, but for repair of small areas air drying touch-up paint intended for brush application is available from paint suppliers. Your painted sheet supplier should be contacted for precise information. This touch-up paint cannot be expected to exhibit the same weathering and other characteristics as the original painted sheet, and touched-up areas will present appearance differences after weather exposure. For this reason, use of touch-up paint should be held to a minimum.

Many types of paint systems are used, and it is difficult to establish reasonable and meaningful standards for all of them. Specific applications require consideration of life expectancy, forming requirements and methods, economics, and so forth. Paint systems generally in use exhibit general characteristics as shown on *Aluminum Standards and Data 2009* pages 7-31 to 7-33, but for specific applications consult the painted sheet supplier.

These are the characteristics that give aluminum its extreme versatility. In the majority of applications, two or more of these characteristics come prominently into play—for example, light weight combined with strength in airplanes, railroad cars, trucks and other transportation equipment. High resistance to corrosion and high thermal conductivity are important in equipment for the chemical and petroleum industries; these properties combine with nontoxicity for food processing equipment.

Attractive appearance together with high resistance to weathering and low maintenance requirements have led to extensive use in buildings of all types. High reflectivity, excellent weathering characteristics, and light weight are all important in roofing materials. Light weight contributes to low handling and shipping costs, whatever the application.

Many applications require the extreme versatility that only aluminum has. Almost daily its unique combination of properties is being put to work in new ways. The metal now serves as a basic raw material for more than 20,000 businesses scattered throughout the country.

2. Aluminum Metallurgy

In high-purity form aluminum is soft and ductile. Most commercial uses, however, require greater strength than pure aluminum affords. This is achieved in aluminum first by the addition of other elements to produce various alloys, which singly or in combination impart strength to the metal. Further strengthening is possible by means that classify the alloys roughly into two categories, non-heat-treatable and heat-treatable.

Non-heat-treatable alloys—The initial strength of alloys in this group depends upon the hardening effect of elements such as manganese, silicon, iron and magnesium, singly or in various combinations. The non-heat-treatable alloys are usually designated, therefore, in the 1xxx, 3xxx, 4xxx, or 5xxx series. Since these alloys are work-hardenable, further strengthening is made possible by various degrees of cold working, denoted by the "H" series of tempers. Alloys containing appreciable amounts of magnesium when supplied in strain-hardened tempers are usually given a final elevated-temperature treatment called stabilizing to ensure stability of properties.

Heat-treatable alloys—The initial strength of alloys in this group is enhanced by the addition of alloying elements such as copper, magnesium, zinc, and silicon. Since these elements singly or in various combinations show increasing solid solubility in aluminum with increasing temperature, it is possible to subject them to thermal treatments that will impart pronounced strengthening.

The first step, called heat treatment or solution heat treatment, is an elevated-temperature process designed to put the soluble element or elements in solid solution. This is followed by rapid quenching, usually in water, which momentarily "freezes" the structure and for a short time renders the alloy very workable. It is at this stage that some fabricators retain this more workable structure by storing the alloys at below freezing temperatures until they are ready to form them. At room or elevated temperatures the alloys are not stable after quenching, however, and precipitation of the constituents from the super-saturated solution begins. After a period of several days at room temperature, termed aging or room-temperature precipitation, the alloy is considerably stronger. Many alloys approach a stable condition at room temperature, but some alloys, particularly those containing magnesium and silicon or magnesium and zinc, continue to age-harden for long periods of time at room temperature.

By heating for a controlled time at slightly elevated temperatures, even further strengthening is possible and properties are stabilized. This process is called artificial aging or precipitation hardening. By the proper combination of solution heat treatment, quenching, cold working and artificial aging, the highest strengths are obtained.

Clad alloys—The heat-treatable alloys in which copper or zinc are major alloying constituents are less resistant to corrosive attack than the majority of non-heat-treatable alloys. To increase the corrosion resistance of these alloys in sheet and plate form, they are often clad with high-purity aluminum, a low magnesium-silicon alloy, or an alloy containing 1 percent zinc. The cladding, usually from 2½ percent to 5 percent of the total thickness on each side, not only protects the composite due to its own inherently excellent corrosion resistance but also exerts a galvanic effect, which further protects the core material.

Special composites may be obtained such as clad non-heat-treatable alloys for extra corrosion protection, for brazing purposes, or for special surface finishes. Some alloys in wire and tubular form are clad for similar reasons, and on an experimental basis extrusions also have been clad.

Annealing characteristics—All wrought aluminum alloys are available in annealed form. In addition, it may be desirable to anneal an alloy from any other initial temper, after working, or between successive stages of working such as in deep drawing.

3. Wrought Aluminum and Aluminum Alloy Designation System ①

A system of four-digit numerical designations is used to identify wrought aluminum and wrought aluminum alloys. The first digit indicates the alloy group as follows:

Aluminum, 99.00 percent and greater	1xxx
Aluminum alloys grouped by major alloying elements ② ③ ④	
Copper	2xxx
Manganese	3xxx
Silicon	4xxx
Magnesium	5xxx
Magnesium and silicon	6xxx
Zinc	7xxx
Other element	8xxx
Unused series	9xxx

The designation assigned shall be in the 1xxx group whenever the minimum aluminum content is specified as 99.00 percent or higher. The alloy designation in the 2xxx through 8xxx groups is determined by the alloying element (Mg_2Si for 6xxx alloys) present in the greatest mean percentage, except in cases in which the alloy being registered qualifies as a modification or national variation of a previously registered alloy. If the greatest mean percentage is common to more than one alloying element, choice of group will be in order of group sequence Cu, Mn, Si, Mg, Mg_2Si, Zn or others.

The last two digits identify the aluminum alloy or indicate the aluminum purity. The second digit indicates modifications of the original alloy or impurity limits.

3.1 Aluminum

In the 1xxx group for minimum aluminum purities of 99.00 percent and greater, the last two of the four digits in the designation indicate the minimum aluminum percentage.⑤ These digits are the same as the two digits to the right of the decimal point in the minimum aluminum percentage when it is expressed to the nearest 0.01 percent. The second digit in the designation indicates modifications in impurity limits or alloying elements. If the second digit in the designation is zero, it indicates unalloyed aluminum having natural impurity limits; integers 1 through 9, which are assigned consecutively as needed, indicate special control of one or more individual impurities or alloying elements.

3.2 Aluminum Alloys

In the 2xxx through 8xxx alloy groups the last two of the four digits in the designation have no special significance but serve only to identify the different aluminum alloys in the group. The second digit in the alloy designation indicates alloy modifications. If the second digit in the designation is zero, it indicates the original alloy; integers 1 through 9, which are assigned consecutively, indicate alloy modifications. A modification of the original alloy is limited to any one or a combination of the following:

(a) Change of not more than the following amounts in arithmetic mean of the limits for an individual alloying element or combination of elements expressed as an alloying element or both.

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① Chemical composition limits and designations conforming to this standard for wrought aluminum and wrought aluminum alloys, and aluminum and aluminum alloy castings and foundry ingot may be registered with The Aluminum Association provided: (1) the aluminum or aluminum alloy is offered for sale, (2) the complete chemical composition limits are registered, and (3) the composition is significantly different from that of any aluminum or aluminum alloy for which a numerical designation already has been assigned.

② For codification purposes an alloying element is any element that is intentionally added for any purpose other than grain refinement and for which minimum and maximum limits are specified.

③ Standard limits for alloying elements and impurities are expressed to the following places:

Less than .001 percent	0.000X
.001 but less than .01 percent	0.00X
.01 but less than .10 percent	
Unalloyed aluminum made by a refining process	0.0XX
Alloys and unalloyed aluminum not made by a refining process	0.0X
.10 through .55 percent	0.XX
(It is customary to express limits of 0.30 percent through 0.55 percent as 0.X0 or 0.X5)	
Over .55 percent	0.X, X.X, etc.
(except that combined Si + Fe limits for 1xxx designations must be expressed as 0.XX or 1.XX)	

④ Standard limits for alloying elements and impurities are expressed in the following sequence: Silicon; Iron; Copper; Manganese; Magnesium; Chromium; Nickel; Zinc; Titanium (see Note 1); Other (see Note 2) Elements, Each; Other (see Note 2) Elements, Total; Aluminum (see Note 3).

Note 1—Additional specified elements having limits are inserted in alphabetical order according to their chemical symbols between Titanium and Other Elements, Each, or are listed in footnotes.

Note 2—"Other" includes listed elements for which no specific limit is shown as well as unlisted metallic elements. The producer may analyze samples for trace elements not specified in the registration or specification. However, such analysis is not required and may not cover all metallic "other" elements. Should any analysis by the producer or the purchaser establish that an "other" element exceeds the limit of "Each" or that the aggregate of several "other" elements exceeds the limit of "Total", the material shall be considered non-conforming.

Note 3—Aluminum is specified as minimum for unalloyed aluminum, and as a remainder for aluminum alloys.

⑤ The aluminum content for unalloyed aluminum made by a refining process is the difference between 100.00 percent and the sum of all other metallic elements plus silicon present in amounts of 0.0010 percent or more, each expressed to the third decimal before determining the sum, which is rounded to the second decimal before subtracting; for unalloyed aluminum not made by a refining process it is the difference between 100.00 percent and the sum of all other analyzed metallic elements plus silicon present in amounts of 0.010 percent or more, each expressed to the second decimal before determining the sum. For unalloyed aluminum made by a refining process, when the specified maximum limit is 0.0XX, an observed value or a calculated value greater than 0.0005 but less than 0.0010% is rounded off and shown as "less than 0.001"; for alloys and unalloyed aluminum not made by a refining process, when the specified maximum limit is 0.XX, an observed value or a calculated value greater than 0.005 but less than 0.010% is rounded off and shown as "less than 0.01".

Arithmetic Mean of Limits for Alloying Elements in Original Alloy	Maximum Change
Up thru 1.0 percent	0.15
Over 1.0 thru 2.0 percent	0.20
Over 2.0 thru 3.0 percent	0.25
Over 3.0 thru 4.0 percent	0.30
Over 4.0 thru 5.0 percent	0.35
Over 5.0 thru 6.0 percent	0.40
Over 6.0 percent	0.50

To determine compliance when maximum and minimum limits are specified for a combination of two or more elements in one alloy composition, the arithmetic mean of such a combination is compared to the sum of the mean values of the same individual elements, or any combination thereof, in another alloy composition.

(b) Addition or deletion of not more than one alloying element with limits having an arithmetic mean of not more than 0.30 percent or addition or deletion of not more than one combination of elements expressed as an alloying element with limits having a combined arithmetic mean of not more than 0.40 percent.

(c) Substitution of one alloying element for another element serving the same purpose.

(d) Change in limits for impurities expressed singly or as a combination.

(e) Change in limits for grain refining elements.

(f) Maximum iron or silicon limits of 0.12 percent and 0.10 percent, or less, respectively, reflecting use of high purity base metal.

An alloy shall not be registered as a modification if it meets the requirements for a national variation.

3.3 Experimental Alloys

Experimental alloys are also designated in accordance with this system, but they are indicated by the prefix X. The prefix is dropped when the alloy is no longer experimental. During development and before they are designated as experimental, new alloys are identified by serial numbers assigned by their originators. Use of the serial number is discontinued when the X number is assigned.

3.4 National Variations

National variations of wrought aluminum and wrought aluminum alloys registered by another country in accordance with this system are identified by a serial letter following the numerical designation. The serial letters are assigned internationally in alphabetical sequence starting with A but omitting I, O and Q.

A national variation has composition limits that are similar but not identical to those registered by another country, with differences such as:

(a) Change of not more than the following amounts in arithmetic mean of the limits for an individual alloying element or combination of elements expressed as an alloying element, or both:

Arithmetic Mean of Limits for Alloying Elements in Original Alloy or modification	Maximum Change
Up thru 1.0 percent	0.15
Over 1.0 thru 2.0 percent	0.20
Over 2.0 thru 3.0 percent	0.25
Over 3.0 thru 4.0 percent	0.30
Over 4.0 thru 5.0 percent	0.35
Over 5.0 thru 6.0 percent	0.40
Over 6.0 percent	0.50

To determine compliance when maximum and minimum limits are specified for a combination of two or more elements in one alloy composition, the arithmetic mean of such a combination is compared to the sum of the mean values of the same individual elements, or any combination thereof, in another alloy composition.

(b) Substitution of one alloying element for another element serving the same purpose.

(c) Different limits on impurities except for low iron. Iron maximum of 0.12 percent, or less, reflecting high purity base metal, should be considered as an alloy modification.

(d) Different limits on grain refining elements.

(e) Inclusion of a minimum limit for iron or silicon, or both.

Wrought aluminum and wrought aluminum alloys meeting these requirements shall not be registered as a new alloy or alloy modification.

4. Cast Aluminum and Aluminum Alloy Designation System ①

A system of four digit numerical designations is used to identify aluminum and aluminum alloys in the form of castings and foundry ingot. The first digit indicates the alloy group as follows:

Aluminum, 99.00 percent minimum and greater	1xx.x
Aluminum alloys grouped by major alloying elements ②③④	
Copper	2xx.x
Silicon, with added copper and/or magnesium	3xx.x
Silicon	4xx.x
Magnesium	5xx.x
Zinc	7xx.x
Tin	8xx.x
Other element	9xx.x
Unused series	6xx.x

The alloy group in the 2xx.x through 9xx.x excluding 6xx.x alloys is determined by the alloying element present in the greatest mean percentage, except in cases in which the alloy being registered qualified as a modification of a previously registered alloy. If the greatest mean percentage is common to more than one alloying element, the alloy group will be determined by the sequence shown above.

The second two digits identify the aluminum alloy or indicate the aluminum purity. The last digit, which is separated from the others by a decimal point, indicates the product form: that is, castings or ingot. A modification of the original alloy or impurity limits is indicated by a serial letter before the numerical designation. The serial letters are assigned in alphabetical sequence starting with A but omitting I, O, Q and X, the X being reserved for experimental alloys.

A modification of the original alloy is limited to any one or a combination of the following:

(a) Change of not more than the following amounts in the arithmetic mean of the limits for an individual alloying element or combination of elements expressed as an alloying element or both:

Arithmetic Mean of Limits for Alloying Elements in Original Alloy	Maximum Change
Up thru 1.0 percent	0.15
Over 1.0 thru 2.0 percent	0.20
Over 2.0 thru 3.0 percent	0.25
Over 3.0 thru 4.0 percent	0.30
Over 4.0 thru 5.0 percent	0.35
Over 5.0 thru 6.0 percent	0.40
Over 6.0 percent	0.50

To determine compliance when maximum and minimum limits are specified for a combination of two or more elements in one alloy composition, the arithmetic mean of such a combination is compared to the sum of the mean values of the same individual elements, or any combination thereof, in another alloy composition.

(b) Addition or deletion of not more than one alloying element with limits having an arithmetic mean of not more than 0.30 percent or addition or deletion of not more than one combination of elements expressed as an alloying element with limits having a combined arithmetic mean of not more than 0.40 percent.

(c) Substitution of one alloying element for another element serving the same purpose.

(d) Change in limits for impurities expressed singly or as a combination.

(e) Change in limits for grain refining elements.

(f) Iron or silicon maximum limits of 0.12 percent and 0.10 percent, or less, respectively, reflecting use of high purity base metal.

4.1 Aluminum Castings and Ingot

In the 1xx.x group for minimum aluminum purities of 99.00 percent and greater, the second two of the four digits in the designation indicate the minimum aluminum percentage.⑤ These digits are the same as the two digits to the right of the decimal point in the minimum aluminum percentage when it is expressed to the nearest 0.01 percent. The last digit, which is to the right of the decimal point, indicates the product form: 1xx.0 indicates castings, and 1xx.1 indicates ingot.

4.2 Aluminum Alloy Castings and Ingot

In the 2xx.x through 9xx.x alloy groups the second two of the four digits in the designation have no special significance but serve only to identify the different aluminum alloys in the group. The last digit, which is to the right of the decimal point, indicates the product form: xxx.0 indicates castings, xxx.1 indicates ingot that has chemical composition limits conforming to 3.2.1, and xxx.2 indicates ingot that has chemical composition limits that differ but fall within the limits of xxx.1 ingot.

4.2.1 Limits for Alloying Elements and Impurities

Limits for alloying elements and impurities for xxx.1 ingot are the same as for the alloy in the form of castings, except for the following:

Maximum Iron Percentage:

For All Forms of Castings	*For Ingot, Fe shall be Least*
Up thru 0.15	0.03 less than castings
Over 0.15 thru 0.25	0.05 less than castings
Over 0.25 thru 0.6	0.10 less than castings
Over 0.6 thru 1.0	0.2 less than castings
Over 1.0	0.3 less than castings

Minimum Magnesium Percentage*:

For All Forms of Castings	*For Ingot*
Less than 0.50	0.05 more than castings
0.50 and greater	0.1 more than castings

Maximum Zinc Percentage:

For Die Castings	*For Ingot*
Over 0.25 thru 0.6	0.10 less than castings
Over 0.6	0.1 less than castings

For all numbered footnotes, see page IV-9.

*Applicable only if the resulting magnesium range is 0.15 percent or greater.

4.2.2 Identifiers for 3xx.x and 4xx.x Foundry Ingot containing Structure Modifiers

One of the applicable suffixes in the table below should be added to the registered alloy designation whenever a structure modifier is intentionally added to that alloy.

Alloy Designation Suffix	Structure Modifying Element	Chemical Composition Limits Minimum (%)	Maximum (%)
N	Na	0.003	0.08
S	Sr	0.005	0.08
C	Ca	0.005	0.15
P	P	—	0.060

(a) The letter suffix follows and is separated from the registered foundry ingot designation by a hyphen (e.g., "A356.1-S")

(b) In cases where more than one modifier is intentionally added, only the modifier of greater concentration shall be identified by suffix letter affixed to the registered alloy designation.

(c) Where a foundry alloy is sold with a suffix added to its alloy designation, the modifying element's concentration is not to be included in "Others, Each" or "Others, Total".

(d) It is not intended that these structure modifier identifiers be treated as new alloy registration, not should these designations be listed in the Registration Record.

4.3 Experimental Alloys

Experimental alloys are also designated in accordance with this system, but they are indicated by the prefix X. The prefix is dropped when the alloy is no longer experimental. During development and before they are designated as experimental, new alloys are identified by serial numbers assigned by their originators. Use of the serial number is discontinued when the X number is assigned.

5. Effect of Alloying Elements

1xxx series—Aluminum of 99 percent or higher purity has many applications, especially in the electrical and chemical fields. These compositions are characterized by excellent corrosion resistance, high thermal and electrical conductivity, low mechanical properties and excellent workability. Moderate increases in strength may be obtained by strain-hardening. Iron and silicon are the major impurities.

2xxx series—Copper is the principal alloying element in this group. These alloys require solution heat-treatment to obtain optimum properties; in the heat treated condition mechanical properties are similar to, and sometimes exceed, those of mild steel. In some instances artificial aging is employed to further increase the mechanical properties. This treatment materially increases yield strength, with attendant loss in elongation; its effect on tensile (ultimate) strength is not so great. The alloys in the 2xxx series do not have as good corrosion resistance as most other aluminum alloys, and under certain conditions they may be subject to intergranular corrosion. Therefore, these alloys in the form of sheet are usually clad with a high-purity alloy or a magnesium-silicon alloy of the 6xxx series, which provides galvanic protection to the core material and thus greatly increases resistance to corrosion. Alloy 2024 is perhaps the best known and most widely used aircraft alloy.

3xxx series—Manganese is the major alloying element of alloys in this group, which are generally non-heat-treatable. Because only a limited percentage of manganese, up to about 1.5 percent, can be effectively added to aluminum, it is used as a major element in only a few instances. One of these, however, is the popular 3003, which is widely used as a general purpose alloy for moderate-strength applications requiring good workability.

4xxx series—The major alloying element of this group is silicon, which can be added in sufficient quantities to cause substantial lowering of the melting point without producing brittleness in the resulting alloys. For these reasons aluminum-silicon alloys are used in welding wire and as brazing alloys where a lower melting point than that of the parent metal is required. Most alloys in this series are non-heat-treatable, but when used in welding heat-treatable alloys they will pick up some of the alloying constituents of the latter and so respond to heat treatment to a limited extent. The alloys containing appreciable amounts of silicon become dark grey when anodic oxide finishes are applied, and hence are in demand for architectural applications.

5xxx series—Magnesium is one of the most effective and widely used alloying elements for aluminum. When it is used as the major alloying element or with manganese, the result is a moderate to high strength non-heat-treatable alloy. Magnesium is considerably more effective than manganese as a hardener, about 0.8 percent magnesium being equal to 1.25 percent manganese, and it can be added in considerably higher quantities. Alloys in this series possess good welding characteristics and good resistance to corrosion in marine atmosphere. However, certain limitations should be placed on the amount of cold work and on the safe operating temperatures permissible for the higher magnesium content alloys (over about 3½ percent for operating temperatures above about 150°F) to avoid susceptibility to stress corrosion.

6xxx series—Alloys in this group contain silicon and magnesium in approximate proportions to form magnesium silicide, thus making them heat-treatable. The major alloy in this series is 6061, one of the most versatile of the heat-treatable alloys. Though less strong than most of the 2xxx or 7xxx alloys, the magnesium-silicon (or magnesium-silicide) alloys possess good formability and corrosion resistance, with medium strength. Alloys in this heat-treatable group may be formed in the T4 temper (solution heat-treated but not artificially aged) and then reach full T6 properties by artificial aging.

7xxx series—Zinc is the major alloying element in this group, and when coupled with a smaller percentage of magnesium results in heat-treatable alloys of very high strength. Usually other elements such as copper and chromium are also added in small quantities. The outstanding member of this group is 7075, which is among the highest strength alloys available and is used in air-frame structures and for highly stressed parts.

6. Temper Designation System ⑥

The temper designation system is used for all forms of wrought and cast aluminum and aluminum alloys except ingot. It is based on the sequences of basic treatments used to produce the various tempers. The temper designation follows the alloy designation, the two being separated by a hyphen. Basic temper designations consist of letters. Subdivisions of the basic tempers, where required, are indicated by one or more digits following the letter. These designate specific sequences of basic treatments, but only operations recognized as significantly influencing the characteristics of the product are indicated. Should some other variation of the same sequence of basic operations be applied to the same alloy, resulting in different characteristics, then additional digits are added to the designation.

6.1 Basic Temper Designations

F **as fabricated.** Applies to the products of shaping processes in which no special control over thermal conditions or strain hardening is employed. For wrought products, there are no mechanical property limits.

O **annealed.** Applies to wrought products that are annealed to obtain the lowest strength temper, and to cast products that are annealed to improve ductility and dimensional stability. The O may be followed by a digit other than zero.

H **strain-hardened (wrought products only).** Applies to products that have their strength increased by strain-hardening, with or without supplementary thermal treatments to produce some reduction in strength. The H is always followed by two or more digits.

W **solution heat-treated.** An unstable temper applicable only to alloys that spontaneously age at room temperature after solution heat-treatment. This designation is specific only when the period of natural aging is indicated; for example: W ½ hr.

T **thermally treated to produce stable tempers other than F, O, or H.** Applies to products that are thermally treated, with or without supplementary strain-hardening, to produce stable tempers. The T is always followed by one or more digits.

6.2 Subdivisions of Basic Tempers

6.2.1 Subdivision of H Temper: Strain-hardened

6.2.1.1 The first digit following the H indicates the specific combination of basic operations, as follows:

H1 **strain-hardened only.** Applies to products that are strain-hardened to obtain the desired strength without supplementary thermal treatment. The number following this designation indicates the degree of strain-hardening.

H2 **strain-hardened and partially annealed.** Applies to products that are strain-hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing. For alloys that age-soften at room temperature, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H3 tempers. For other alloys, the H2 tempers have the same minimum ultimate tensile strength as the corresponding H1 tempers and slightly higher elongation. The number following this designation indicates the degree of strain-hardening remaining after the product has been partially annealed.

H3 **strain-hardened and stabilized.** Applies to products that are strain-hardened and whose mechanical properties are stabilized either by a low temperature thermal treatment or as a result of heat introduced during fabrication. Stabilization usually improves ductility. This designation is applicable only to those alloys that, unless stabilized, gradually age-soften at room temperature. The number following this designation indicates the degree of strain-hardening remaining after the stabilization treatment.

H4 **strain-hardened and lacquered or painted.** Applies to products which are strain-hardened and which are subjected to some thermal operation during the subsequent painting or lacquering operation. The number following this designation indicates the degree of strain-hardening remaining after the product has been thermally treated, as part of painting/lacquering cure operation. The corresponding H2X or H3X mechanical property limits apply.

6.2.1.2 The digit following the designation H1, H2, H3, and H4 indicates the degree of strain-hardening as identified by the minimum value of the ultimate tensile strength. Numeral 8 has been assigned to the hardest tempers normally produced. The minimum tensile strength of tempers HX8 may be determined from Table 1 and is based on the minimum tensile strength of the alloy in the annealed temper. However, temper registrations prior to 1992 that do not conform to the requirements of Table 1 shall not be revised and registrations of intermediate or modified tempers for such alloy/temper systems shall conform to the registration requirements that existed prior to 1992.

Table 1

US Customary Units

Minimum tensile strength in annealed temper ksi	Increase in tensile strength to HX8 temper ksi
up to 6	8
7 to 9	9
10 to 12	10
13 to 15	11
16 to 18	12
19 to 24	13
25 to 30	14
31 to 36	15
37 to 42	16
43 and over	17

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⑥ Temper designations conforming to this standard for wrought aluminum and wrought aluminum alloys, and aluminum alloy castings may be registered with the Aluminum Association provided: (1) the temper is used or is available for use by more than one user, (2) mechanical property limits are registered, (3) the characteristics of the temper are significantly different from those of all other tempers that have the same sequence of basic treatments and for which designations already have been assigned for the same alloy and product, and (4) the following are also registered if characteristics other than mechanical properties are considered significant: (a) test methods and limits for the characteristics or (b) the specific practices used to produce the temper.

Metric Units

Minimum tensile strength in annealed temper MPa	Increase in tensile strength to HX8 temper MPa
up to 40	55
45 to 60	65
65 to 80	75
85 to 100	85
105 to 120	90
125 to 160	95
165 to 200	100
205 to 240	105
245 to 280	110
285 and 320	115
325 and over	120

Tempers between O (annealed) and HX8 are designated by numerals 1 through 7.

(a) Numeral 4 designates tempers whose ultimate tensile strength is approximately midway between that of the O temper and that of the HX8 tempers;

(b) Numeral 2 designates tempers whose ultimate tensile strength is approximately midway between that of the O temper and that of the HX4 tempers;

(c) Numeral 6 designates tempers whose ultimate tensile strength is approximately midway between that of the HX4 tempers and that of the HX8 tempers;

(d) Numerals 1, 3, 5 and 7 designate, similarly, tempers intermediate between those defined above.

(e) Numeral 9 designates tempers whose minimum ultimate tensile strength exceeds that of the HX8 tempers by 2 ksi or more. (For Metric Units by 10 MPa or more).

The ultimate tensile strength of the odd numbered intermediate (-HX1, -HX3, -HX5, and HX7) tempers, determined as described above, shall be rounded to the nearest multiple of 0.5 ksi. (For Metric Units when not ending in 0 or 5 shall be rounded to the next higher 0 or 5 MPa).

6.2.1.3 The third digit,⑦ when used, indicates a variation of a two-digit temper. It is used when the degree of control of temper or the mechanical properties or both differ from, but are close to, that (or those) for the two-digit H temper designation to which it is added, or when some other characteristic is significantly affected. (See Appendix for assigned three-digit H tempers.) NOTE: The minimum ultimate tensile strength of a three-digit H temper must be at least as close to that of the corresponding two-digit H temper as it is to the adjacent two-digit H tempers. Products in the H temper whose mechanical properties are below H__1 shall be variations of H__1.

6.2.2 Subdivision of T Temper: Thermally Treated

6.2.2.1 Numerals 1 through 10 following the T indicate specific sequences of basic treatments, as follows:⑧

T1	**cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition.** Applies to products that are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.
T2	**cooled from an elevated temperature shaping process, cold worked, and naturally aged to a substantially stable condition.** Applies to products that are cold worked to improve strength after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.
T3	**solution heat-treated,⑨ cold worked, and naturally aged to a substantially stable condition.** Applies to products that are cold worked to improve strength after solution heat-treatment, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.
T4	**solution heat-treated ⑨ and naturally aged to a substantially stable condition.** Applies to products that are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.
T5	**cooled from an elevated temperature shaping process and then artificially aged.** Applies to products that are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.
T6	**solution heat-treated ⑨ and then artificially aged.** Applies to products that are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognized in mechanical property limits.
T7	**solution heat-treated⑨ and overaged/stabilized.** Applies to wrought products that are artificially aged after solution heat-treatment to carry them beyond a point of maximum strength to provide control of some significant characteristic⑩. Applies to cast products that are artificially aged after solution heat-treatment to provide dimensional and strength stability.
T8	**solution heat-treated,⑨ cold worked, and then artificially aged.** Applies to products that are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.
T9	**solution heat-treated,⑨ artificially aged, and then cold worked.** Applies to products that are cold worked to improve strength.
T10	**cooled from an elevated temperature shaping process, cold worked, and then artificially aged.** Applies to products that are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in mechanical property limits.

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⑦ Numerals 1 through 9 may be arbitrarily assigned as the third digit and registered with the Aluminum Association for an alloy and product to indicate a variation of a two-digit H temper (see note ⑥).

⑧ A period of natural aging at room temperature may occur between or after the operations listed for the T tempers. Control of this period is exercised when it is metallurgically important.

⑨ Solution heat treatment is achieved by heating cast or wrought products to a suitable temperature, holding at that temperature long enough to allow constituents to enter into solid solution and cooling rapidly enough to hold the constituents in solution. Some 6xxx series alloys attain the same specified mechanical properties whether furnace solution heat treated or cooled from an elevated temperature shaping process at a rate rapid enough to hold constituents in solution. In such cases the temper designations T3, T4, T6, T7, T8, and T9 are used to apply to either process and are appropriate designations.

⑩ For this purpose, *characteristic* is something other than mechanical properties. The test method and limit used to evaluate material for this characteristic are specified at the time of the temper registration.

6.2.2.2 Additional digits,⑪ the first of which shall not be zero, may be added to designations T1 through T10 to indicate a variation in treatment that significantly alters the product characteristics that are or would be obtained using the basic treatment. (See Appendix for specific additional digits for T tempers.)

APPENDIX

6.3 Variations of O Temper: Annealed

A digit following the O, when used, indicates a product in the annealed condition having special characteristics. NOTE: As the O temper is not part of the strain-hardened (H) series, variations of O temper shall not apply to products that are strain-hardened after annealing and in which the effect of strain-hardening is recognized in the mechanical properties or other characteristics.

A1 Three-Digit H Tempers

(a) The following three-digit H temper designations have been assigned for wrought products in all alloys:

H_11 Applies to products that incur sufficient strain hardening after the final anneal that they fail to qualify as annealed but not so much or so consistent an amount of strain hardening that they qualify as H_1.

H112 Applies to products that may acquire some temper from working at an elevated temperature and for which there are mechanical property limits.

(b) The following three-digit H temper designations have been assigned for

pattern or embossed sheet	fabricated from
H114	O temper
H124, H224, H324	H11, H21, H31 temper, respectively
H134, H234, H334	H12, H22, H32 temper, respectively
H144, H244, H344	H13, H23, H33 temper, respectively
H154, H254, H354	H14, H24, H34 temper, respectively
H164, H264, H364	H15, H25, H35 temper, respectively
H174, H274, H374	H16, H26, H36 temper, respectively
H184, H284, H384	H17, H27, H37 temper, respectively
H194, H294, H394	H18, H28, H38 temper, respectively
H195, H295, H395	H19, H29, H39 temper, respectively

(c) The following three-digit H temper designations have been assigned only for wrought products in the 5xxx series, for which the magnesium content is 3% nominal or more:

H116 Applies to products manufactured from alloys in the 5xxx series, for which the magnesium content is 3% nominal or more. Products are normally strain hardened at the last operation to specified stable tensile property limits and meet specified levels of corrosion resistance in accelerated type corrosion tests. They are suitable for continuous service at temperature no greater than 150°F (66°C). Corrosion tests include inter-granular and exfoliation.

H321 Applies to products from alloys in the 5xxx series, for which the magnesium content is 3% nominal or more. Products are normally thermally stabilized at the last operation to specified stable tensile property limits and meet specified levels of corrosion resistance in accelerated type corrosion tests. They are suitable for continuous service at temperatures no greater than 150°F (66°C). Corrosion tests include inter-granular and exfoliation.

A2 Additional Digits for T Tempers

A2.1 Assigned Additional Digits for Stress-Relieved Temper

The following specific additional digits have been assigned for stress-relieved tempers of wrought products:

A2.1.1 Stress relieved by stretching⑫

T_51 Applies to plate and rolled or cold-finished rod or bar, die or ring forgings and rolled rings when stretched the indicated amounts after solution heat treatment or after cooling from an elevated temperature shaping process. The products receive no further straightening after stretching.

Plate	1½% to 3% permanent set.
Rolled or Cold-Finished Rod and Bar	1% to 3% permanent set.
Die or Ring Forgings and Rolled Rings	1% to 5% permanent set.

T_510 Applies to extruded rod, bar, profiles (shapes) and tube and to drawn tube when stretched the indicated amounts after solution heat treatment or after cooling from an elevated temperature shaping process. These products receive no further straightening after stretching.

Extruded Rod Bar, Profiles (Shapes) and Tube	1% to 3% permanent set.
Drawn Tube	½% to 3% permanent set.

T_511 Applies to extruded rod, bar, profiles (shapes) and tube and to drawn tube when stretched the indicated amounts after solution heat treatment or after cooling from an elevated temperature shaping process. These products may receive minor straightening after stretching to comply with standard tolerances.

Extruded Rod, Bar, Profiles (Shapes) and Tube	1% to 3% permanent set.
Drawn Tube	½% to 3% permanent set.

A2.1.2 Stress relieved by compressing⑫

T_52 Applies to products that are stress-relieved by compressing after solution heat treatment or cooling from an elevated temperature shaping process to produce a permanent set of 1 percent to 5 percent.

A2.1.3 Stress relieved by combined stretching and compressing⑫

T_54 Applies to die forgings that are stress relieved by restriking cold in the finish die.

A2.2 Assigned Additional Digits for T7 Temper Variations

The following temper designations have been assigned for wrought products which are artificially overaged to obtain a

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⑪ Additional digits may be arbitrarily assigned and registered with The Aluminum Association for an alloy and product to indicate a variation of tempers T1 through T10 even though the temper representing the basic treatment has not been registered (see note ⑥). Variations in treatment that do not alter the characteristics of the product are considered alternate treatments for which additional digits are not assigned.

⑫ The same digits (51, 510, 511, 52, 54) may be added to the designation W to indicate unstable solution heat-treated and stress-relieved tempers.

good comprise among exfoliation corrosion resistance, stress corrosion resistance, fracture toughness, and tensile strength.

The designations shall be applied when standardizing new alloy-temper-product combinations.

T79	Very limited overaging to achieve some improved corrosion resistance with limited reduction in strength as compared to the T6 temper.
T76	Limited overaged condition to achieve moderate corrosion resistance with some reduction in strength. The T76 temper has lower strength and better corrosion resistance than the T79 temper.
T74	Overaged condition to achieve good corrosion resistance with a greater reduction in strength than the T76 temper. The T74 temper strength and corrosion resistance properties are between those of the T73 and T76 tempers.
T73	Fully overaged condition to achieve the best corrosion resistance of the T7X tempers with a greater reduction in strength than the T74 temper.
T77	Aged condition which provides strength at or near T6 temper and corrosion resistance similar to T76 temper corrosion resistance similar to T76 temper.

The evolution of material properties from temper T79 to T73 is illustrated in Figure 1.*

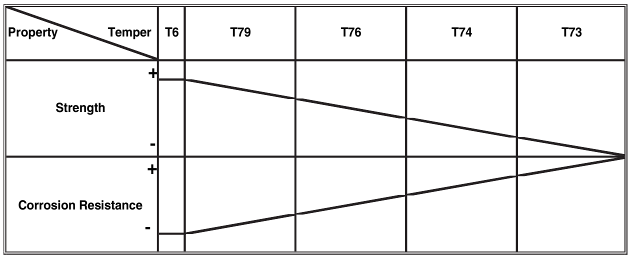

Figure 1

* The T77 temper does not fall within the continuous progression of the T7X tempers depicted in Figure 1.

A2.3 Assigned Temper Designations for Producer/ Supplier and Purchaser/User Heat Treatment

A2.3.1 Temper Designations for Producer/ Supplier Laboratory Demonstration of Response to Heat-treatment:

The following temper designations have been assigned for wrought products test material, furnace heat-treated from annealed (O, O1, etc.) or F temper, to demonstrate response to heat-treatment.

T42	Solution heat-treated from annealed or F temper and naturally aged to a substantially stable condition.
T62	Solution heat-treated from annealed or F temper and artificially aged.
T7_2	Solution heat-treated from annealed or F temper and artificially overaged to meet the mechanical properties and corrosion resistance limits of the T7_ temper.

A2.3.2 Temper Designations for Producer/ Supplier Demonstration of Response to Temper Conversion:

Temper designation T_2 shall be used to indicate wrought product test material, which has undergone furnace heat-treatment for capability demonstration of temper conversion. When the purchaser requires capability demonstrations from T-temper, the seller shall note “Capability Demonstration” adjacent to the specified and ending tempers. Some examples are:

(a) “-T3 to -T82 Capability Demonstration for response to aging”;

(b) “-T4 to -T62 Capability Demonstration for response to aging”;

(c) “-T4 to -T762 Capability Demonstration for response to overaging”;

(d) “-T6 to -T732 Capability Demonstration for response to overaging”;

(e) “-T351 to -T42 Capability Demonstration for response to re-solution heat-treatment”.

A2.3.3 Temper Designation for Purchaser/ User Heat-treatment

Temper designation T_2 should also be applied to wrought products heat-treated by the purchaser/user, in accordance with the applicable heat treatment specification, to achieve the properties applicable to the final temper.

A3 Assigned O Temper Variations

The following temper designation has been assigned for wrought products high temperature annealed to accentuate ultrasonic response and provide dimensional stability.

O1	Thermally treated at approximately same time and temperature required for solution heat treatment and slow cooled to room temperature. Applicable to products that are to be machined prior to solution heat treatment by the user. Mechanical property limits are not applicable.

A4 Designation of Unregistered Tempers

A4.1 The letter P has been assigned to denote H, T and O temper variations that are negotiated between manufacturer and purchaser. The letter P immediately follows the temper designation that most nearly pertains. Specific examples where such designation may be applied include the following:

(a) The use of the temper is sufficiently limited so as to preclude its registration. (Negotiated H temper variations were formerly indicated by the third digit zero.)

(b) The test conditions (sampling location, number of samples, test specimen configuration, etc.) are different from those required for registration with The Aluminum Association.

(c) The mechanical property limits are not established on the same basis as required for registration with The Aluminum Association.

(d) For products such as Aluminum Metal Matrix Composites which are not included in any registration records.

Table 1
COMPARATIVE CHARACTERISTICS AND APPLICATIONS

ALLOY AND TEMPER	RESISTANCE TO CORROSION		Workability (Cold) ⑤	Machinability ⑤	Brazeability ⑥	WELDABILITY ⑥			SOME APPLICATIONS OF ALLOYS
	General ①	Stress-Corrosion Cracking ②				Gas	Arc	Resistance Spot and Seam	
1060-O	A	A	A	E	A	A	A	B	Chemical equipment, railroad tank cars
H12	A	A	A	E	A	A	A	A	
H14	A	A	A	D	A	A	A	A	
H16	A	A	B	D	A	A	A	A	
H18	A	A	B	D	A	A	A	A	
1100-O	A	A	A	E	A	A	A	B	Sheet metal work, spun hollowware, fin stock
H12	A	A	A	E	A	A	A	A	
H14	A	A	A	D	A	A	A	A	
H16	A	A	B	D	A	A	A	A	
H18	A	A	C	D	A	A	A	A	
1350-O	A	A	A	E	A	A	A	B	Electrical conductors
H12, H111	A	A	A	E	A	A	A	A	
H14, H24	A	A	A	D	A	A	A	A	
H16, H26	A	A	B	D	A	A	A	A	
H18	A	A	B	D	A	A	A	A	
2011-T3	D ③	D	C	A	D	D	D	D	Screw machine products
T4, T451	D ③	D	B	A	D	D	D	D	
T8	D	B	D	A	D	D	D	D	
2014-O	. .	. .	. .	D	D	D	D	B	Truck frames, aircraft structures
T3, T4, T451	D ③	C	C	B	D	D	B	B	
T6, T651, T6510, T6511	D	C	D	B	D	D	B	B	
2017-T4, T451	D ③	C	C	B	D	D	B	B	Screw machine products, fittings
2018-T61	. .	. .	. .	B	D	D	C	B	Aircraft engine cylinders, heads and pistons
2024-O	. .	. .	. .	D	D	D	D	D	Truck wheels, screw machine products, aircraft structures
T4, T3, T351, T3510, T3511	D ③	C	C	B	D	C	B	B	
T361	D ③	C	D	B	D	D	C	B	
T6	D	B	C	B	D	D	C	B	
T861, T81, T851, T8510, T8511	D	B	D	B	D	D	C	B	
T72	. .	. .	. .	B	D	D	C	B	
2025-T6	D	C	. .	B	D	D	B	B	Forgings, aircraft propellers
2036-T4	C	. .	B	C	D	C	B	B	Auto body panel sheet
2117-T4	C	A	B	C	D	D	B	B	Rivets
2124-T851	D	B	D	B	D	D	C	B	Aircraft structures
2218-T61	D	C	. .	. .	D	D	C	B	Jet engine impellers and rings
T72	D	C	. .	B	D	D	C	B	
2219-O	. .	. .	. .	. .	D	D	A	B	Structural uses at high temperatures (to 600°F) High strength weldments
T31, T351, T3510, T3511	D ③	C	C	B	D	A	A	A	
T37	D ③	C	D	B	D	A	A	A	
T81, T851, T8510, T8511	D	B	D	B	D	A	A	A	
T87	D	B	D	B	D	A	A	A	
2618-T61	D	C	. .	B	D	D	C	B	Aircraft engines
3003-O	A	A	A	E	A	A	A	B	Cooking utensils, chemical equipment, pressure vessels, sheet metal work, builder's hardware, storage tanks
H12	A	A	A	E	A	A	A	A	
H14	A	A	B	D	A	A	A	A	
H16	A	A	C	D	A	A	A	A	
H18	A	A	C	D	A	A	A	A	
H25	A	A	B	D	A	A	A	A	
3004-O	A	A	A	D	B	A	A	B	Sheet metal work, storage tanks
H32	A	A	B	D	B	A	A	A	
H34	A	A	B	C	B	A	A	A	
H36	A	A	C	C	B	A	A	A	
H38	A	A	C	C	B	A	A	A	

For all numbered footnotes, see page IV-20.

Table 1
COMPARATIVE CHARACTERISTICS AND APPLICATIONS (Continued)

ALLOY AND TEMPER	RESISTANCE TO CORROSION		Workability (Cold) ⑤	Machinability ⑤	Brazeability ⑥	WELDABILITY ⑥			SOME APPLICATIONS OF ALLOYS
	General ①	Stress-Corrosion Cracking ②				Gas	Arc	Resistance Spot and Seam	
3105-O	A	A	A	E	A	A	A	B	Residential siding, mobile homes, rain carrying goods, sheet metal work
H12	A	A	B	E	A	A	A	A	
H14	A	A	B	D	A	A	A	A	
H16	A	A	C	D	A	A	A	A	
H18	A	A	C	D	A	A	A	A	
H25	A	A	B	D	A	A	A	A	
4032-T6	C	B	. .	B	D	D	B	C	Pistons
5005-O	A	A	A	E	B	A	A	B	Appliances, utensils, architectural, electrical conductor
H12	A	A	A	E	B	A	A	A	
H14	A	A	B	D	B	A	A	A	
H16	A	A	C	D	B	A	A	A	
H18	A	A	C	D	B	A	A	A	
H32	A	A	A	E	B	A	A	A	
H34	A	A	B	D	B	A	A	A	
H36	A	A	C	D	B	A	A	A	
H38	A	A	C	D	B	A	A	A	
5050-O	A	A	A	E	B	A	A	B	Builder’s hardware, refrigerator trim, coiled tubes
H32	A	A	A	D	B	A	A	A	
H34	A	A	B	D	B	A	A	A	
H36	A	A	C	C	B	A	A	A	
H38	A	A	C	C	B	A	A	A	
5052-O	A	A	A	D	C	A	A	B	Sheet metal work, hydraulic tube, appliances
H32	A	A	B	D	C	A	A	A	
H34	A	A	B	C	C	A	A	A	
H36	A	A	C	C	C	A	A	A	
H38	A	A	C	C	C	A	A	A	
5056-O	A ④	B ④	A	D	D	C	A	B	Cable sheathing, rivets for magnesium, screen wire, zipper
H111	A ④	B ④	A	D	D	C	A	A	
H12, H32	A ④	B ④	B	D	D	C	A	A	
H14, H34	A ④	B ④	B	C	D	C	A	A	
H18, H38	A ④	C ④	C	C	D	C	A	A	
H192	B ④	D ④	D	B	D	C	A	A	
H392	B ④	D ④	D	B	D	C	A	A	
5083-O	A ④	A ④	B	D	D	C	A	B	
H321 ⑧	A ④	A ④	C	D	D	C	A	A	
H111	A ④	B ④	C	D	D	C	A	A	
H116 ⑧	A ④	A ④	C	D	D	C	A	A	
5086-O	A ④	A ④	A	D	D	C	A	B	Unfired, welded pressure vessels, marine, auto aircraft cryogenics, TV towers, drilling rigs, transportation equipment, missile components
H32 ⑧	A ④	A ④	B	D	D	C	A	A	
H34	A ④	B ④	B	C	D	C	A	A	
H36	A ④	B ④	C	C	D	C	A	A	
H38	A ④	B ④	C	C	D	C	A	A	
H111	A ④	A ④	B	D	D	C	A	A	
H116 ⑧	A ④	A ④	B	D	D	C	A	A	
5154-O	A ④	A ④	A	D	D	C	A	B	Welded structures, storage tanks, pressure vessels, salt water service
H32	A ④	A ④	B	D	D	C	A	A	
H34	A ④	A ④	B	C	D	C	A	A	
H36	A ④	A ④	C	C	D	C	A	A	
H38	A ④	A ④	C	C	D	C	A	A	
5252-H24	A	A	B	D	C	A	A	A	Automotive and appliance trim
H25	A	A	B	C	C	A	A	A	
H28	A	A	C	C	C	A	A	A	

For all numbered footnotes, see page IV-20.

Table 1
COMPARATIVE CHARACTERISTICS AND APPLICATIONS (Continued)

ALLOY AND TEMPER	RESISTANCE TO CORROSION		Workability (Cold) ⑤	Machinability ⑤	Brazeability ⑥	WELDABILITY ⑥			SOME APPLICATIONS OF ALLOYS
	General ①	Stress-Corrosion Cracking ②				Gas	Arc	Resistance Spot and Seam	
5254-O	A ④	A ④	A	D	D	C	A	B	Hydrogen peroxide and chemical storage vessels
H32	A ④	A ④	B	D	D	C	A	A	
H34	A ④	A ④	B	C	D	C	A	A	
H36	A ④	A ④	C	C	D	C	A	A	
H38	A ④	A ④	C	C	D	C	A	A	
5454-O	A	A	A	D	D	C	A	B	Welded structures, pressure vessels, marine service
H32	A	A	B	D	D	C	A	A	
H34	A	A	B	C	D	C	A	A	
H111	A	A	B	D	D	C	A	A	
5456-O	A ④	B ④	B	D	D	C	A	B	High strength welded structures, pressure vessels, marine applications, storage tanks
H321 ⑧	A ④	B ④	C	D	D	C	A	A	
H116 ⑧	A ④	B ④	C	D	D	C	A	A	
5457-O	A	A	A	E	B	A	A	B	
5652-O	A	A	A	D	C	A	A	B	Hydrogen peroxide and chemical storage vessels
H32	A	A	B	D	C	A	A	A	
H34	A	A	B	C	C	A	A	A	
H36	A	A	C	C	C	A	A	A	
H38	A	A	C	C	C	A	A	A	
5657-H241	A	A	A	D	B	A	A	A	Anodized auto and appliance trim
H25	A	A	B	D	B	A	A	A	
H26	A	A	B	D	B	A	A	A	
H28	A	A	C	D	B	A	A	A	
6005-T1, T5	. .	. .	. .	. .	A	A	A	A	
6053-O	. .	. .	. .	E	B	A	A	B	Wire and rod for rivets
T6, T61	A	A	. .	C	B	A	A	A	
6061-O	B	A	A	D	A	A	A	B	Heavy-duty structures requiring good corrosion resistance, truck and marine, railroad cars, furniture, pipelines
T4, T451, T4510, T4511	B	B	B	C	A	A	A	A	
T6, T651, T652, T6510, T6511	B	A	C	C	A	A	A	A	
6063-T1	A	A	B	D	A	A	A	A	Pipe railing, furniture, architectural extrusions
T4	A	A	B	D	A	A	A	A	
T5, T452	A	A	B	C	A	A	A	A	
T6	A	A	C	C	A	A	A	A	
T83, T831, T832	A	A	C	C	A	A	A	A	
6066-O	C	A	B	D	D	D	B	B	Forgings and extrusion for welded structures
T4, T4510, T4511	C	B	C	C	D	D	B	B	
T6, T6510, T6511	C	B	C	B	D	D	B	B	
6070-T4, T4511	B	B	B	C	D	A	A	A	Heavy duty welded structures, pipelines
T6	B	B	C	C	D	A	A	A	
6101-T6, T63	A	A	C	C	A	A	A	A	High strength bus conductors
T61, T64	A	A	B	D	A	A	A	A	
6151-T6, T652	. .	. .	. .	. .	B	. .	. .	. .	Moderate strength, intricate forgings for machine and auto parts
6201-T81	A	A	. .	C	A	A	A	A	High strength electric conductor wire
6262-T6, T651, T6510, T6511	B	A	C	B	B	B	B	A	Screw machine products
T9	B	A	D	B	B	B	B	A	
6351-T1	. .	. .	C	C	C	B	A	B	Extruded shapes, structurals, pipe and tube
T4	A	. .	C	C	C	B	A	B	
T5	A	. .	C	C	C	B	A	A	
T6	A	. .	C	C	C	B	A	A	

For all numbered footnotes, see page IV-20.

Table 1
COMPARATIVE CHARACTERISTICS AND APPLICATIONS (Continued)

ALLOY AND TEMPER	RESISTANCE TO CORROSION		Workability (Cold) ⑤	Machinability ⑤	Brazeability ⑥	WELDABILITY ⑥			SOME APPLICATIONS OF ALLOYS
	General ①	Stress-Corrosion Cracking ②				Gas	Arc	Resistance Spot and Seam	
6463-T1	A	A	B	D	A	A	A	A	Extruded architectural and trim sections
T5	A	A	B	C	A	A	A	A	
T6	A	A	C	C	A	A	A	A	
6951-T42, T62	. .	. .	. .	. .	A	A	A	A	
7005-T53	. .	. .	. .	. .	B	C	A	A	
7049-T73, T7352	C	B	D	B	D	D	D	B	Aircraft forgings
7050-T73510, T73511 T74 ⑦, T7451 ⑦, T74510 ⑦, T74511 ⑦, T7452 ⑦, T7651, T76510, T76511	C	B	D	B	D	D	D	B	Aircraft and other structures
7075-O	. .	. .	. .	D	D	D	D	B	Aircraft and other structures
T6, T651, T652, T6510, T6511	C ③	C	D	B	D	D	D	B	
T73, T7351	C	B	D	B	D	D	D	B	
7175-T74, T7452, T7454	C	B	D	B	D	D	C	B	
7178-O	. .	. .	. .	. .	D	D	D	B	Aircraft and other structures
T6, T651, T6510, T6511	C ③	C	D	B	D	D	D	B	
7475-O	. .	. .	. .	. .	D	D	D	B	Shell Casings
7475-T61, -T651	C	C	D	B	D	D	B	B	Aircraft & Other
7475-T761, T7351	C	B	D	B	D	D	D	B	Structures
8017-H12, H22, H221	A	A	A	D	A	A	A	A	Electrical conductors
8030-H12, H221	A	A	A	E	A	A	A	A	Electrical conductors
8176-H14, H24	A	A	A	D	A	A	A	A	Electrical conductors

① Ratings A through E are relative ratings in decreasing order of merit, based on exposures to sodium chloride solution by intermittent spraying or immersion. Alloys with A and B ratings can be used in industrial and seacoast atmospheres without protection. Alloys with C, D and E ratings generally should be protected at least on faying surfaces.

② Stress-corrosion cracking ratings are based on service experience and on laboratory tests of specimens exposed to the 3.5% sodium chloride alternate immersion test.

A = No known instance of failure in service or in laboratory tests.

B = No known instance of failure in service; limited failures in laboratory tests of short transverse specimens.

C = Service failures with sustained tension stress acting in short transverse direction relative to grain structure; limited failures in laboratory tests of long transverse specimens.

D = Limited service failures with sustained longitudinal or long transverse areas.

These ratings are neither product specific nor test direction specific and therefore indicate only the general level of stress-corrosion cracking resistance. For more specific information on certain alloys, see ASTM G64.

③ In relatively thick sections the rating would be E.

④ This rating may be different for material held at elevated temperature for long periods.

⑤ Ratings A through D for Workability (cold), and A through E for Machinability, are relative ratings in decreasing order of merit.

⑥ Ratings A through D for Weldability and Brazeability are relative ratings defined as follows:

A = Generally weldable by all commercial procedures and methods.

B = Weldable with special techniques or for specific applications that justify preliminary trials or testing to develop welding procedure and weld performance.

C = Limited weldability because of crack sensitivity or loss in resistance to corrosion and mechanical properties.

D = No commonly used welding methods have been developed.

⑦ T74 type tempers, although not previously registered, have appeared in various literature and specifications as T736 type tempers.

⑧ 5xxx products in the -H116 and H32X tempers have similar mechanical properties; however, production methods and testing requirements differ, and these tempers are not interchangeable. The -H116 temper is typically used in marine and other applications requiring demonstration of exfoliation resistance.

Table 2
FOREIGN ALLOY DESIGNATIONS AND SIMILAR AA ALLOYS

Foreign Alloy Designation	Designating Country	Equivalent or Similar AA Alloy
Al99	Austria (Önorm) ①	1200
Al99,5		1050
E-Al		1350
AlCuMg1		2017
AlCuMg2		2024
AlCuMg0,5		2117
AlMg5		5056
AlMgSi0,5		6063
E-AlMgSi		6101
AlZnMgCu1,5		7075
990C	Canada (CSA) ②	1100
CB60		2011
CG30		2117
CG42		2024
CG42 Alclad		Alclad 2024
CM41		2017
CN42		2018
CS41N		2014
CS41N Alclad		Alclad 2014
CS41P		2025
GM31N		5454
GM41		5083
GM50P		5356
GM50R		5056
GR20		5052
GS10		6063
GS11N		6061
GS11P		6053
MC10		3003
S5		4043
SG11P		6151
SG121		4032
ZG62		7075
ZG62 Alclad		Alclad 7075
A5/L	France (NF) ③	1350
A45		1100
A-G1		5050
A-G0.6		5005
A-G4MC		5086
A-GS		6063
A-GS/L		6101
A-M1		3003
A-M1G		3004
A-U4G		2017
A-U2G		2117
A-U2GN		2618
A-U4G1		2024
A-U4N		2218
A-U4SG		2014
A-S12UN		4032
A-Z5GU		7075
E-A1995 ④ 3.0257 ⑤	Germany	1350
AlCuBiPb ④ 3.1655 ⑤		2011
AlCuMg0.5 ④ 3.1305 ⑤		2117
AlCuMg1 ④ 3.1325 ⑤		2017
AlCuMg2 ④ 3.1355 ⑤		2024
AlCuSiMn ④ 3.1255 ⑤		2014
AlMg4.5Mn ④ 3.3547 ⑤		5083
AlMgSi0.5 ④ 3.3206 ⑤		6063
AlSi5 ④ 3.2245 ⑤		4043
E-AlMgSi0.5 ④ 3.3207 ⑤		6101
AlZnMgCu1.5 ④ 3.4365 ⑤		7075
1E	Great Britain (BS) ⑥	1350
91E		6101
H14		2017
H19		6063
H20		6061
L.80, L.81		5052
L.86		2117
L.87		2117
L.93, L.94		2014A
L.95, L.96		7075
L.97, L.98		2024
2L.55, 2L.56		5052
2L.58		5056
3L.44		5050
5L.37		2017
6L.25		2218
N8		5083
N21		4043
150A	Great Britain (DTD) ⑦	2017
324A		4032
372B		6063
717, 724, 731A 745, 5014, 5084		2618
5090		2024
5100		Alclad 2024
P-AlCu4MgMn	Italy (UNI) ⑧	2017
P-AlCu4.5MgMn		2024
P-AlCu4.5MgMnplacc.		Alclad 2024
P-AlCu2.5MgSi		2117
P-AlCu4.4SiMnMg		2014
P-AlCu4.4SiMnMgplacc.		Alclad 2014
P-AlMg0.9		5657
P-AlMg1.5		5050
P-AlMg2.5		5052
P-AlSi0.4Mg		6063
P-AlSi0.5Mg		6101
Al99.5E	Spain (UNE) ⑨	1350
L-313		2014
L-314		2024
L-315		2218
L-371		7075
Al-Mg-Si	Switzerland (VSM) ⑩	6101
Al1.5Mg		5050
Al-Cu-Ni		2218
Al3.5Cu0.5Mg		2017
Al4Cu1.2Mg		2027
Al-Zn-Mg-Cu		7075
Al-Zn-Mg-Cu-pl		Alclad 7075
Al99.0Cu	ISO ⑪	1100
AlCu2Mg		2117
AlCu4Mg1		2024
AlCu4SiMg		2014
AlCu4MgSi		2017
AlMg1		5005
AlMg1.5		5050
AlMg2.5		5052
AlMg3.5		5154
AlMg4		5086
AlMg5		5056
AlMn1Cu		3003
AlMg3Mn		5454
AlMg4.5Mn		5083
AlMgSi		6063
AlMg1SiCu		6061
AlZn6MgCu		7075

① Austrian Standard M3430.
② Canadian Standards Association.
③ Normes Françaises.
④ Deutsche Industrie-Norm.
⑤ Werkstoff-Nr.
⑥ British Standard.
⑦ Directorate of Technical Development.
⑧ Unificazione Nazionale Italiana.
⑨ Una Norma Espanol.
⑩ Verein Schweizerischer Maschinenindustrieller.
⑪ International Organization for Standardization.

Table 3
MECHANICAL PROPERTY LIMITS FOR COMMONLY USED ALUMINUM SAND CASTING ALLOYS ①

Alloy	Temper ②	MINIMUM PROPERTIES					Typical Brinell Hardness ④ 500 – kgf load 10 – mm ball
		Tensile Strength				% Elongation in 2 inches or 4 times diameter	
		Ultimate		Yield (0.2% Offset)			
		ksi	(MPa)	ksi	(MPa)		
201.0	T7	60.0	(415)	50.0	(345)	3.0	110–140
204.0	T4	45.0	(310)	28.0	(195)	6.0	—
208.0	F	19.0	(130)	12.0	(85)	1.5	40–70
222.0	0	23.0	(160)	—	—	—	65–95
222.0	T61	30.0	(205)	—	—	—	100–130
242.0	0	23.0	(160)	—	—	—	55–85
242.0	T571	29.0	(200)	—	—	—	70–100
242.0	T61	32.0	(220)	20.0	(140)	—	90–120
242.0	T77	24.0	(165)	13.0	(90)	1.0	60–90
295.0	T4	29.0	(200)	13.0	(90)	6.0	45–75
295.0	T6	32.0	(220)	20.0	(140)	3.0	60–90
295.0	T62	36.0	(250)	28.0	(195)	—	80–110
295.0	T7	29.0	(200)	16.0	(110)	3.0	55–85
319.0	F	23.0	(160)	13.0	(90)	1.5	55–85
319.0	T5	25.0	(170)	—	—	—	65–95
319.0	T6	31.0	(215)	20.0	(140)	1.5	65–95
328.0	F	25.0	(170)	14.0	(95)	1.0	45–75
328.0	T6	34.0	(235)	21.0	(145)	1.0	65–95
355.0	T51	25.0	(170)	18.0	(125)	—	50–80
355.0	T6	32.0	(220)	20.0	(140)	2.0	70–105
355.0	T7	35.0	(240)	—	—	—	70–100
355.0	T71	30.0	(205)	22.0	(150)	—	60–95
C355.0	T6	35.0	(250)	25.0	(170)	2.5	75–105
356.0	F	19.0	(130)	—	—	2.0	40–70
356.0	T51	23.0	(160)	16.0	(110)	—	45–75
356.0	T6	30.0	(205)	20.0	(140)	3.0	55–90
356.0	T7	31.0	(215)	29.0	(200)	—	60–90
356.0	T71	25.0	(170)	18.0	(125)	3.0	45–75
A356.0	T6	34.0	(235)	24.0	(165)	3.5	70–105
357.0	—	—	—	—	—	—	—
A357.0	—	—	—	—	—	—	—
359.0	—	—	—	—	—	—	—
443.0	F	17.0	(115)	7.0	(50)	3.0	25–55
B433.0	F	17.0	(115)	6.0	(40)	3.0	25–55
512.0	F	17.0	(115)	10.0	(70)	—	35–65
514.0	F	22.0	(150)	9.0	(60)	6.0	35–65
520.0	T4 ⑤	42.0	(290)	22.0	(150)	12.0	60–90
535.0	F or T5	35.0	(240)	18.0	(125)	9.0	60–90
705.0	F or T5	30.0	(205)	17.0	(115)	5.0	50–80
707.0	T5	33.0	(230)	22.0	(150)	2.0	70–100
707.0	T7	37.0	(255)	30.0	(205)	1.0	65–95
710.0	F or T5	32.0	(220)	20.0	(140)	2.0	60–90
712.0	F or T5	34.0	(235)	25.0	(170)	4.0	60–90
713.0	F or T5	32.0	(220)	22.0	(150)	3.0	60–90
771.0	T5	42.0	(290)	38.0	(260)	1.5	85–115
771.0	T51	32.0	(220)	27.0	(165)	3.0	70–100
771.0	T52	36.0	(250)	30.0	(205)	1.5	70–100
771.0	T53	36.0	(250)	27.0	(185)	1.5	—
771.0	T6	42.0	(290)	35.0	(240)	5.0	75–105
771.0	T71	48.0	(330)	45.0	(310)	2.0	105–135
850.0	T5	16.0	(110)	—	—	5.0	30–60
851.0	T5	17.0	(115)	—	—	3.0	30–60
852.0	T5	24.0	(165)	18.0	(125)	—	45–75

① Values represent properties obtained from separately cast lest bars and are derived from ASTM 8-26, Standard Specification for Aluminum-Alloy Sand Castings; Federal Specification QQ-A-601e, Aluminum Alloy Sand Castings; and Military Specification MIL-A-21180c, Aluminum Alloy Castings, High Strength. Unless otherwise specified, the tensile strength, yield strength and elongation values of specimens cut from castings shall be not less than 75 percent of the tensile and yield strength values and not less than 25 percent of the elongation values given above. The customer should keep in mind that (1) some foundries may offer additional tempers for the above alloys, and (2) foundries are constantly improving casting techniques and, as a result, some may offer minimum properties in excess of the above. If quality level 4 castings are specified as described in Table 1 of AA-CS-M5-85, no tensile tests shall be specified nor tensile requirements be met on specimens cut from castings.

② F indicates “as cast” condition; refer to AA-CS-M11 for recommended times and temperatures of heat treatment for other tempers to achieve properties specified.

③ Footnote no longer in use.

④ Hardness values are given for information only; not required for acceptance.

⑤ The T4 temper of Alloy 520.0 is unstable; significant room temperature aging occurs within life expectancy of most castings. Elongation may decrease by as much as 80 percent.

Table 4
MECHANICAL PROPERTY LIMITS FOR COMMONLY USED PERMANENT MOLD CASTING ALLOYS ①

Alloy	Temper ②	MINIMUM PROPERTIES					Typical Brinell Hardness ③ 500 – kgf load 10 – mm ball
		Tensile Strength				% Elongation in 2 inches or 4 times diameter	
		Ultimate		Yield (0.2% Offset)			
		ksi	(MPa)	ksi	(MPa)		
204.0	T4	48.0	(330)	29.0	(200)	8.0	—
208.0	T4	33.0	(230)	15.0	(105)	4.5	60–90
208.0	T6	35.0	(240)	22.0	(150)	2.0	75–105
208.0	T7	33.0	(230)	16.0	(110)	3.0	65–95
222.0	T551	30.0	(205)	—	—	—	100–130
222.0	T65	40.0	(275)	—	—	—	125–155
242.0	T571	34.0	(230)	—	—	—	90–120
242.0	T61	40.0	(275)	—	—	—	95–125
298.0	T6	35.0	(240)	—	—	2.0	75–105
308.0	F	24.0	(165)	—	—	2.0	55–85
319.0	F	28.0	(195)	14.0	(95)	1.5	70–100
319.0	T6	34.0	(235)	—	—	2.0	75–105
332.0	T5	31.0	(215)	—	—	—	90–120
333.0	F	28.0	(195)	—	—	—	65–100
333.0	T5	30.0	(205)	—	—	—	70–106
333.0	T6	35.0	(240)	—	—	—	65–115
333.0	T7	31.0	(215)	—	—	—	75–105
336.0	T551	31.0	(215)	—	—	—	90–120
336.0	T65	40.0	(275)	—	—	—	110–140
354.0	T61	48.0	(330)	37.0	(255)	3.0	—
354.0	T62	52.0	(360)	42.0	(290)	2.0	—
355.0	T51	27.0	(185)	—	—	—	60–90
355.0	T6	37.0	(255)	—	—	1.5	75–105
355.0	T62	42.0	(290)	—	—	—	90–120
355.0	T7	36.0	(250)	—	—	—	70–100
355.0	T71	34.0	(235)	27.0	(185)	—	85–95
C355.0	T61	40.0	(275)	30.0	(205)	3.0	75–105
356.0	F	21.0	(145)	—	—	3.0	40–70
356.0	T51	25.0	(170)	—	—	—	55–85
356.0	T6	33.0	(230)	22.0	(150)	3.0	65–95
356.0	T7	25.0	(170)	—	—	3.0	60–90
356.0	T71	25.0	(170)	—	—	3.0	60–90
A356.0	T61	37.0	(255)	26.0	(180)	5.0	70–100
357.0	T6	45.0	(310)	—	—	3.0	75–105
A357.0	T61	45.0	(310)	36.0	(250)	3.0	85–115
359.0	T61	45.0	(310)	34.0	(235)	4.0	75–105
359.0	T62	47.0	(325)	38.0	(260)	3.0	85–115
443.0	F	21.0	(145)	7.0	(50)	2.0	30–60
B443.0	F	21.0	(145)	6.0	(40)	2.5	30–60
A444.0	T4	20.0	(140)	—	—	20.0	—
513.0	F	22.0	(150)	12.0	(85)	2.5	45–75
535.0	F	35.0	(240)	18.0	(125)	8.0	60–90
705.0	T5	37.0	(255)	17.0	(120)	10.0	55–85
707.0	T7	45.0	(310)	35.0	(240)	3.0	80–110
711.0	T1	28.0	(195)	18.0	(125)	7.0	55–86
713.0	T5	32.0	(220)	22.0	(150)	4.0	60–90
850.0	T5	18.0	(125)	—	—	8.0	30–60
851.0	T5	17.0	(115)	—	—	3.0	30–60
851.0	T6	16.0	(125)	—	—	8.0	—
852.0	T5	27.0	(185)	—	—	3.0	55–85

① Values represent properties obtained from separately cast test bars and are derived from ASTM B-108, Standard Specification for Aluminum-Alloy Permanent Mold Castings; Federal Specification QQ-A-596d, Aluminum Alloy Permanent and Semi-Permanent Mold Castings; and Military Specification MIL-A-21180c, Aluminum Alloy Castings, High Strength. Unless otherwise specified, the average tensile strength, average yield strength and average elongation values of specimens cut from castings shall be not less than 75 percent of the tensile strength and yield values and not less than 25 percent of the elongation values given above. The customer should keep in mind that (1) some foundries may offer additional tempers for the above alloys, and (2) foundries are constantly improving casting techniques and, as a result, some may offer minimum properties in excess of the above.

② F indicates "as cast" condition; refer to AA-CS-M11 for recommended times and temperatures of heat treatment for other tempers to achieve properties specified.

③ Hardness values are given for information only; not required for acceptance.

Table 5
MECHANICAL PROPERTY LIMITS OF FASTENER ALLOYS ①

ALLOY AND TEMPER	SPECIFIED DIAMETER in.	TENSILE STRENGTH ksi min.		ELONGATION ② percent min. in. 2 in. or 4D ③	ULTIMATE SHEARING STRENGTH ksi min.
		ULTIMATE	YIELD ②		
2017-T4	0.063–1.000	55.0	32.0	12	33.0
2024-T42	0.063–0.124	62.0	. .	. .	37.0
	0.125–1.000	62.0	40.0	10	37.0
2117-T4	0.063–1.000	38.0	18.0	18	26.0
2219-T6	0.063–1.000	55.0	35.0	6	30.0
6053-T61	0.063–1.000	30.0	20.0	14	20.0
6061-T6	0.063–1.000	42.0	35.0	10	25.0
7050-T7	0.063–1.000	70.0	58.0	10	39.0
7075-T6	0.063–1.000	77.0	66.0	7	42.0
7075-T73	0.063–1.000	68.0	56.0	10	41.0
7178-T6	0.063–1.000	84.0	73.0	5	46.0

① Rivet and cold heading wire and rod, and the fasteners produced from it, shall upon proper heat treatment (T4 and T42 tempers) or heat treatment and aging (T6, T61, T7 and T73 tempers) be capable of developing the properties presented in Table 10.4. Tensile tests are preferred for the rivet and cold heading wire and rod, and shear tests for the fasteners made from it.
② The measurement of elongation and yield strength is not required for wire less than 0.125 inch in thickness or diameter.
③ D represents specimen diameter.

Table 5M
MECHANICAL PROPERTY LIMITS OF FASTENER ALLOYS ①

ALLOY AND TEMPER	SPECIFIED DIAMETER mm	TENSILE STRENGTH MPa min		ELONGATION ② percent min		ULTIMATE SHEARING STRENGTH MPa min
		ULTIMATE	YIELD ②	50 mm	5D (5.65 $\sqrt{A}$)	
2017-T4	1.60–25.00	380	220	12	10	225
2024-T42	1.60–3.15	425	. .	. .	. .	255
	3.15–25.00	425	255	10	9	255
2117-T4	1.60–25.00	260	125	18	16	180
2219-T6	1.60–25.00	380	240	6	5	205
6053-T61	1.60–25.00	205	135	14	12	135
6061-T6	1.60–25.00	290	240	10	9	170
7050-T7	1.60–25.00	485	400	10	9	270
7075-T6	1.60–25.00	530	455	7	6	290
7075-T73	1.60–25.00	470	385	10	9	280
7178-T6	1.60–25.00	580	500	5	4	315

① Rivet and cold heading wire and rod, and the fasteners produced from it, shall upon proper heat treatment (T4 and T42 tempers) or heat treatment and aging (T6, T61, T7 and T73 tempers) be capable of developing the properties presented in Table 10.4. Tensile tests are preferred for the rivet and cold heading wire and rod, and shear tests for the fasteners made from it.
② Processes such as flattening, leveling, or straightening coiled products subsequent to shipment by the producer may alter the mechanical properties of the metal.

Table 6
TYPICAL MECHANICAL PROPERTIES ① ②

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size. These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

ALLOY AND TEMPER	TENSION				HARDNESS	SHEAR	FATIGUE	MODULUS
	STRENGTH ksi		ELONGATION percent in 2 in.		BRINNELL NUMBER	ULTIMATE SHEARING STRENGTH	ENDURANCE ③ Limit	MODULUS ④ OF ELASTICTY
	ULTIMATE	YIELD	1/16 in. Thick Specimen	1/2 in. Diameter Specimen	500 kg load 10 mm ball	ksi	ksi	ksi × 10³
1060-O	10	4	43	. .	19	7	3	10.0
1060-H12	12	11	16	. .	23	8	4	10.0
1060-H14	14	13	12	. .	26	9	5	10.0
1060-H16	16	15	8	. .	30	10	6.5	10.0
1060-H18	19	18	6	. .	35	11	6.5	10.0
1100-O	13	5	35	45	23	9	5	10.0
1100-H12	16	15	12	25	28	10	6	10.0
1100-H14	18	17	9	20	32	11	7	10.0
1100-H16	21	20	6	17	38	12	9	10.0
1100-H18	24	22	5	15	44	13	9	10.0
1350-O	12	4	. .	. . ⑤	. .	8	. .	10.0
1350-H12	14	12	. .	. .	. .	9	. .	10.0
1350-H14	16	14	. .	. .	. .	10	. .	10.0
1350-H16	18	16	. .	. .	. .	11	. .	10.0
1350-H19	27	24	. .	. . ⑥	. .	15	7	10.0
2011-T3	55	43	. .	15	95	32	18	10.2
2011-T8	59	45	. .	12	100	35	18	10.2
2014-O	27	14	. .	18	45	18	13	10.6
2014-T4, T451	62	42	. .	20	105	38	20	10.6
2014-T6, T651	70	60	. .	13	135	42	18	10.6
Alclad 2014-O	25	10	21	. .	. .	18	. .	10.5
Alclad 2014-T3	63	40	20	. .	. .	37	. .	10.5
Alclad 2014-T4, T451	61	37	22	. .	. .	37	. .	10.5
Alclad 2014-T6, T651	68	60	10	. .	. .	41	. .	10.5
2017-O	26	10	. .	22	45	18	13	10.5
2017-T4, T451	62	40	. .	22	105	38	18	10.5
2018-T61	61	46	. .	12	120	39	17	10.8
2024-O	27	11	20	22	47	18	13	10.6
2024-T3	70	50	18	. .	120	41	20	10.6
2024-T4, T351	68	47	20	19	120	41	20	10.6
2024-T361 ⑦	72	57	13	. .	130	42	18	10.6
Alclad 2024-O	26	11	20	. .	. .	18	. .	10.6
Alclad 2024-T3	65	45	18	. .	. .	40	. .	10.6
Alclad 2024-T4, T351	64	42	19	. .	. .	40	. .	10.6
Alclad 2024-T361 ⑦	67	63	11	. .	. .	41	. .	10.6
Alclad 2024-T81, T851	65	60	6	. .	. .	40	. .	10.6
Alclad 2024-T861 ⑦	70	66	6	. .	. .	42	. .	10.6
2025-T6	58	37	. .	19	110	35	18	10.4
2036-T4	49	28	24	. .	. .	. .	18 ⑨	10.3
2117-T4	43	24	. .	27	70	28	14	10.3
2124-T851	70	64	. .	8	. .	. .	. .	10.6
2218-T72	48	37	. .	11	95	30	. .	10.8
2219-O	25	11	18	. .	. .	. .	. .	10.6
2219-T42	52	27	20	. .	. .	. .	. .	10.6
2219-T31, T351	52	36	17	. .	. .	. .	. .	10.6
2219-T37	57	46	11	. .	. .	. .	. .	10.6
2219-T62	60	42	10	. .	. .	. .	15	10.6
2219-T81, T851	66	51	10	. .	. .	. .	15	10.6
2219-T87	69	57	10	. .	. .	. .	15	10.6

For all numbered footnotes, see page IV-28.

Table 6
TYPICAL MECHANICAL PROPERTIES (Continued) ① ②

ALLOY AND TEMPER	TENSION				HARDNESS	SHEAR	FATIGUE	MODULUS
	STRENGTH ksi		ELONGATION percent in 2 in.		BRINNELL NUMBER	ULTIMATE SHEARING STRENGTH	ENDURANCE ③ Limit	MODULUS ④ OF ELASTICTY
	ULTIMATE	YIELD	1/16 in. Thick Specimen	½ in. Diameter Specimen	500 kg load 10 mm ball	ksi	ksi	ksi × 10^3
2618-T61	64	54	. .	10	115	38	18	10.8
3003-O	16	6	30	40	28	11	7	10.0
3003-H12	19	18	10	20	35	12	8	10.0
3003-H14	22	21	8	16	40	14	9	10.0
3003-H16	26	25	5	14	47	15	10	10.0
3003-H18	29	27	4	10	55	16	10	10.0
Alclad 3003-O	16	6	30	40	. .	11	. .	10.0
Alclad 3003-H12	19	18	10	20	. .	12	. .	10.0
Alclad 3003-H14	22	21	8	16	. .	14	. .	10.0
Alclad 3003-H16	26	25	5	14	. .	15	. .	10.0
Alclad 3003-H18	29	27	4	10	. .	16	. .	10.0
3004-O	26	10	20	25	45	16	14	10.0
3004-H32	31	25	10	17	52	17	15	10.0
3004-H34	35	29	9	12	63	18	15	10.0
3004-H36	38	33	5	9	70	20	16	10.0
3004-H38	41	36	5	6	77	21	16	10.0
Alclad 3004-O	26	10	20	25	. .	16	. .	10.0
Alclad 3004-H32	31	25	10	17	. .	17	. .	10.0
Alclad 3004-H34	35	29	9	12	. .	18	. .	10.0
Alclad 3004-H36	38	33	5	9	. .	20	. .	10.0
Alclad 3004-H38	41	36	5	6	. .	21	. .	10.0
3105-O	17	8	24	. .	. .	12	. .	10.0
3105-H12	22	19	7	. .	. .	14	. .	10.0
3105-H14	25	22	5	. .	. .	15	. .	10.0
3105-H16	28	25	4	. .	. .	16	. .	10.0
3105-H18	31	28	3	. .	. .	17	. .	10.0
3105-H22	24	20	11	. .	. .	14	. .	10.0
3105-H24	26	22	10			15	. .	10.0
3105-H25	26	23	8	. .	. .	15	. .	10.0
3105-H26	24	24	9	. .	. .	16	. .	10.0
3105-H28	26	26	8	. .	. .	17	. .	10.0
4032-T6	55	46	. .	9	120	38	16	11.4
5005-O	18	6	25	. .	28	11	. .	10.0
5005-H12	20	19	10	. .	. .	14	. .	10.0
5005-H14	23	22	6	. .	. .	14	. .	10.0
5005-H16	26	25	5	. .	. .	15	. .	10.0
5005-H18	29	28	4	. .	. .	16	. .	10.0
5005-H32	20	17	11	. .	36	14	. .	10.0
5005-H34	23	20	8	. .	41	14	. .	10.0
5005-H36	26	24	6	. .	46	15	. .	10.0
5005-H38	29	27	5	. .	51	16	. .	10.0
5050-O	21	8	24	. .	36	15	12	10.0
5050-H32	25	21	9	. .	46	17	13	10.0
5050-H34	28	24	8	. .	53	18	13	10.0
5050-H36	30	26	7	. .	58	19	14	10.0
5050-H38	32	29	6	. .	63	20	14	10.0
5052-O	28	13	25	30	47	18	16	10.2
5052-H32	33	28	12	18	60	20	17	10.2
5052-H34	38	31	10	14	68	21	18	10.2
5052-H36	40	35	8	10	73	23	19	10.2
5052-H38	42	37	7	8	77	24	20	10.2
5056-O	42	22	. .	35	65	26	20	10.3
5056-H18	63	59	. .	10	105	34	22	10.3
5056-H38	60	50	. .	15	100	32	22	10.3

For all numbered footnotes, see page IV-28.

Table 6
TYPICAL MECHANICAL PROPERTIES (Continued) ① ②

ALLOY AND TEMPER	TENSION				HARDNESS	SHEAR	FATIGUE	MODULUS
	STRENGTH ksi		ELONGATION percent in 2 in.		BRINNELL NUMBER	ULTIMATE SHEARING STRENGTH	ENDURANCE ③ Limit	MODULUS ④ OF ELASTICTY
	ULTIMATE	YIELD	$\frac{1}{16}$ in. Thick Specimen	$\frac{1}{2}$ in. Diameter Specimen	500 kg load 10 mm ball	ksi	ksi	ksi × 10^3
5083-O	42	21	. .	22	. .	25	. .	10.3
5083-H116 ⑪	46	33	. .	16	. .	. .	23	10.3
5083-H321	46	33	. .	16	. .	. .	23	10.3
5086-O	38	17	22	. .	. .	23	. .	10.3
5086-H32	42	30	12	. .	. .	. .	. .	10.3
5086-H116 ⑪	42	30	12	. .	. .	. .	. .	10.3
5086-H34	47	37	10	. .	. .	27	. .	10.3
5086-H112	39	19	14	. .	. .	. .	. .	10.3
5154-O	35	17	27	. .	58	22	17	10.2
5154-H32	39	30	15	. .	67	22	18	10.2
5154-H34	42	33	13	. .	73	24	19	10.2
5154-H36	45	36	12	. .	78	26	20	10.2
5154-H38	48	39	10	. .	80	28	21	10.2
5154-H112	35	17	25	. .	63	. .	17	10.2
5252-H25	34	25	11	. .	68	21	. .	10.0
5252-H38, H28	41	35	5	. .	75	23	. .	10.0
5254-O	35	17	27	. .	58	22	17	10.2
5254-H32	39	30	15	. .	67	22	18	10.2
5254-H34	42	33	13	. .	73	24	19	10.2
5254-H36	45	36	12	. .	78	26	20	10.2
5254-H38	48	39	10	. .	80	28	21	10.2
5254-H112	35	17	25	. .	63	. .	17	10.2
5454-O	36	17	22	. .	62	23	. .	10.2
5454-H32	40	30	10	. .	73	24	. .	10.2
5454-H34	44	35	10	. .	81	26	. .	10.2
5454-H111	38	26	14	. .	70	23	. .	10.2
5454-H112	36	18	18	. .	62	23	. .	10.2
5456-O	45	23	. .	24	. .	. .	. .	10.3
5456-H112	45	24	. .	22	. .	. .	. .	10.3
5456-H116 ⑪	51	37	. .	16	90	30	. .	10.3
5456-H321 ⑪	51	37	. .	16	90	30	. .	10.3
5457-O	19	7	22	. .	32	12	. .	10.0
5457-H25	26	23	12	. .	48	16	. .	10.0
5457-H38, H28	30	27	6	. .	55	18	. .	10.0
5652-O	28	13	25	30	47	18	16	10.2
5652-H32	33	28	12	18	60	20	17	10.2
5652-H34	38	31	10	14	68	21	18	10.2
5652-H36	40	35	8	10	73	23	19	10.2
5652-H38	42	37	7	8	77	24	20	10.2
5657-H25	23	20	12	. .	40	12	. .	10.0
5657-H38, H28	28	24	7	. .	50	15	. .	10.0
6061-O	18	8	25	30	30	12	9	10.0
6061-T4, T451	35	21	22	25	65	24	14	10.0
6061-T6, T651	45	40	12	17	95	30	14	10.0
Alclad 6061-O	17	7	25	. .	. .	11	. .	10.0
Alclad 6061-T4, T451	33	19	22	. .	. .	22	. .	10.0
Alclad 6061-T6, T651	42	37	12	. .	. .	27	. .	10.0
6063-O	13	7	. .	. .	25	10	8	10.0
6063-T1	22	13	20	. .	42	14	9	10.0
6063-T4	25	13	22	. .	. .	. .	. .	10.0
6063-T5	27	21	12	. .	60	17	10	10.0
6063-T6	35	31	12	. .	73	22	10	10.0
6063-T83	37	35	9	. .	82	22	. .	10.0
6063-T831	30	27	10	. .	70	18	. .	10.0
6063-T832	42	39	12	. .	95	27	. .	10.0

For all numbered footnotes, see page IV-28

Table 6
TYPICAL MECHANICAL PROPERTIES (Continued) ① ②

ALLOY AND TEMPER	TENSION				HARDNESS	SHEAR	FATIGUE	MODULUS
	STRENGTH ksi		ELONGATION percent in 2 in.		BRINNELL NUMBER	ULTIMATE SHEARING STRENGTH	ENDURANCE ③ Limit	MODULUS ④ OF ELASTICTY
	ULTIMATE	YIELD	1/16 in. Thick Specimen	½ in. Diameter Specimen	500 kg load 10 mm ball	ksi	ksi	ksi × 10^3
6066-O	22	12	. .	18	43	14	. .	10.0
6066-T4, T451	52	30	. .	18	90	29	. .	10.0
6066-T6. T651	57	52	. .	12	120	34	16	10.0
6070-T6	55	51	10	. .	. .	34	14	10.0
6101-H111	14	11	. .	. .	. .	. .	. .	10.0
6101-T6	32	28	15 ⑧	. .	71	20	. .	10.0
6262-T9	58	55	. .	10	120	35	13	10.0
6351-T4	36	22	20	. .	. .	. .	. .	10.0
6351-T6	45	41	14	. .	95	29	13	10.0
6463-T1	22	13	20	. .	42	14	10	10.0
6463-T5	27	21	12	. .	60	17	10	10.0
6463-T6	35	31	12	. .	74	22	10	10.0
7049-T73	75	65	. .	12	135	44	. .	10.4
7049-T7352	75	63	. .	11	135	43	. .	10.4
7050-T73510, T73511	72	63	. .	12	. .	. .	. .	10.4
7050-T7451 ⑩	76	68	. .	11	. .	44	. .	10.4
7050-T7651	80	71	. .	11	. .	47	. .	10.4
7075-O	33	15	17	16	60	22	. .	10.4
7075-T6, T651	83	73	11	11	150	48	23	10.4
Alclad 7075-O	32	14	17	. .	. .	22	. .	10.4
Alclad 7075-T6, T651	76	67	11	. .	. .	46	. .	10.4
7175-T74	76	66	. .	11	135	42	23	10.4
7178-O	33	15	15	16	. .	. .	. .	10.4
7178-T6, T651	88	78	10	11	. .	. .	. .	10.4
7178-T76, T7651	83	73	. .	11	. .	. .	. .	10.3
Alclad 7178-O	32	14	16	. .	. .	. .	. .	10.4
Alclad 7178-T6, T651	81	71	10	. .	. .	. .	. .	10.4
7475-T61	82	71	11	. .	. .	. .	. .	10.2
7475-T651	85	74	. .	13	. .	. .	. .	10.4
7475-T7351	72	61	. .	13	. .	. .	. .	10.4
7475-T761	75	65	12	. .	. .	. .	. .	10.2
7475-T7651	77	67	. .	12	. .	. .	. .	10.4
Alclad 7475-T61	75	66	11	. .	. .	. .	. .	10.2
Alclad 7475-T761	71	61	12	. .	. .	. .	. .	10.2
8176-H24	17	14	15	. .	. .	10	. .	10.0

① The mechanical property limits are listed by major product in the "Standards Section" of this manual.

② The indicated typical mechanical properties for all except 0 temper material are higher than the specified minimum properties. For 0 temper products typical ultimate and yield values are slightly lower than specified (maximum) values.

③ Based on 500,000,000 cycles of completely reversed stress using the R.R. Moore type of machine and specimen.

④ Average of tension and compression moduli. Compression modulus is about 2% greater than tension modulus.

⑤ 1350-O wire will have an elongation of approximately 23% in 10 inches.

⑥ 1350-H19 wire will have an elongation of approximately 1½% in 10 inches.

⑦ Tempers T361 and T861 were formerly designated T36 and T86, respectively.

⑧ Based on ¼ in. thick specimen.

⑨ Based on 10^7 cycles using flexural type testing of sheet specimens.

⑩ T7451, although not previously registered, has appeared in literature and in some specifications as T73651.

⑪ 5xxx products in the -H116 and -H32X tempers have similar mechanical properties; however, production methods and testing requirements differ, and these tempers are not interchangeable. The -H116 temper is typically used in marine and other applications requiring demonstrations of exfoliation resistance.

Table 6M
TYPICAL MECHANICAL PROPERTIES ① ②

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size. These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

ALLOY AND TEMPER	TENSION				HARDNESS	SHEAR	FATIGUE	MODULUS
	STRENGTH MPa		ELONGATION percent		BRINNELL NUMBER	ULTIMATE SHEARING STRENGTH	ENDURANCE ③ LIMIT	MODULUS ④ OF ELASTICITY
	ULTIMATE	YIELD	1.60 mm Thick Specimen	12.5 mm Diameter Specimen	500 kgf load 10 mm ball	MPa	MPa	MPa × 10³
1060-O	70	30	43	. .	19	50	20	69
1060-H12	85	75	16	. .	23	55	30	69
1060-H14	100	90	12	. .	26	60	35	69
1060-H16	115	105	8	. .	30	70	45	69
1060-H18	130	125	6	. .	35	75	45	69
1100-O	90	35	35	42	23	60	35	69
1100-H12	110	105	12	22	28	70	40	69
1100-H14	125	115	9	18	32	75	50	69
1100-H16	145	140	6	15	38	85	60	69
1100-H18	165	150	5	13	44	90	60	69
1350-O	85	30	. .	. . ⑤	. .	55	. .	69
1350-H12	95	85	. .	. .	. .	60	. .	69
1350-H14	110	95	. .	. .	. .	70	. .	69
1350-H16	125	110	. .	. .	. .	75	. .	69
1350-H19	185	165	. .	. . ⑥	. .	105	50	69
2011-T3	380	295	. .	13	95	220	125	70
2011-T8	405	310	. .	10	100	240	125	70
2014-O	185	95	. .	16	45	125	90	73
2014-T4, T451	425	290	. .	18	105	260	140	73
2014-T6, T651	485	415	. .	11	135	290	125	73
Alclad 2014-O	170	70	21	. .	. .	125	. .	73
Alclad 2014-T3	435	275	20	. .	. .	255	. .	73
Alclad 2014-T4, T451	421	255	22	. .	. .	255	. .	73
Alclad 2014-T6, T651	470	415	10	. .	. .	285	. .	73
2017-O	180	70	. .	20	45	125	90	73
2017-T4, T451	425	275	. .	20	105	260	125	73
2018-T61	420	315	. .	10	120	270	115	74
2024-O	185	75	20	20	47	125	90	73
2024-T3	485	345	18	. .	120	285	140	73
2024-T4, T351	472	325	20	17	120	285	140	73
2024-T361 ⑦	495	395	13	. .	130	290	125	73
Alclad 2024-O	180	75	20	. .	. .	125	. .	73
Alclad 2024-T3	450	310	18	. .	. .	275	. .	73
Alclad 2024-T4, T351	440	290	19	. .	. .	275	. .	73
Alclad 2024-T361 ⑦	460	365	11	. .	. .	285	. .	73
Alclad 2024-T81, T851	450	415	6	. .	. .	275	. .	73
Alclad 2024-T861 ⑦	485	455	6	. .	. .	290	. .	73
2025-T6	400	255	. .	17	110	240	125	72
2036-T4	340	195	24	. .	. .	205	125 ⑨	71
2117-T4	295	165	. .	24	70	195	95	71
2124-T851	485	440	. .	8	. .	. .	. .	73
2218-T72	330	255	. .	9	95	205	. .	74
2219-O	170	75	18	. .	. .	. .	. .	73
2219-T42	360	185	20	. .	. .	. .	. .	73
2219-T31, T351	360	250	17	. .	. .	. .	. .	73
2219-T37	395	315	11	. .	. .	. .	. .	73
2219-T62	415	290	10	. .	. .	. .	105	73
2219-T81, T851	455	350	10	. .	. .	. .	105	73
2219-T87	475	395	10	. .	. .	. .	105	73

For all numbered footnotes, see page IV-32.

Table 6M
TYPICAL MECHANICAL PROPERTIES (Continued) ① ②

ALLOY AND TEMPER	TENSION				HARDNESS	SHEAR	FATIGUE	MODULUS
	STRENGTH MPa		ELONGATION percent		BRINNELL NUMBER	ULTIMATE SHEARING STRENGTH	ENDURANCE ③ LIMIT	MODULUS ④ OF ELASTICITY
	ULTIMATE	YIELD	1.60 mm Thick Specimen	12.5mm Diameter Specimen	500 kg load 10 mm ball	MPa	MPa	MPa × 10^3
2618-T61	440	370	. .	10	115	260	90	73
3003-O	110	40	30	37	28	75	50	69
3003-H12	130	125	10	18	35	85	55	69
3003-H14	150	145	8	14	40	95	60	69
3003-H16	175	170	5	12	47	105	70	69
3003-H18	200	185	4	9	55	110	70	69
Alclad 3003-O	110	40	30	37	. .	75	. .	69
Alclad 3003-H12	130	125	10	18	. .	85	. .	69
Alclad 3003-H14	150	145	8	14	. .	95	. .	69
Alclad 3003-H16	175	170	5	12	. .	105	. .	69
Alclad 3003-H18	200	185	4	9	. .	110	. .	69
3004-O	180	70	20	22	45	110	95	69
3004-H32	215	170	10	15	52	115	105	69
3004-H34	240	200	9	10	63	125	105	69
3004-H36	260	230	5	8	70	140	110	69
3004-H38	285	250	5	5	77	145	110	69
Alclad 3004-O	180	70	20	22	. .	110	. .	69
Alclad 3004-H32	215	170	10	15	. .	115	. .	69
Alclad 3004-H34	240	200	9	10	. .	125	. .	69
Alclad 3004-H36	260	230	5	8	. .	140	. .	69
Alclad 3004-H38	285	250	5	5	. .	145	. .	69
3105-O	115	55	24	. .	. .	85	. .	69
3105-H12	150	130	7	. .	. .	95	. .	69
3105-H14	170	150	5	. .	. .	105	. .	69
3105-H16	195	170	4	. .	. .	110	. .	69
3105-H18	215	195	3	. .	. .	115	. .	69
3105-H22	165	140	11	. .	. .	95	. .	69
3105-H24	180	150	10	. .	. .	105	. .	69
3105-H25	185	160	9	. .	. .	105	. .	69
3105-H26	195	165	9	. .	. .	110	. .	69
3105-H28	205	180	8	. .	. .	115	. .	69
4032-T6	380	315	. .	9	120	260	110	79
5005-O	125	40	25	. .	28	75	. .	69
5005-H12	140	130	10	. .	. .	95	. .	69
5005-H14	160	150	6	. .	. .	95	. .	69
5005-H16	180	170	5	. .	. .	105	. .	69
5005-H18	200	195	4	. .	. .	110	. .	69
5005-H32	140	115	11	. .	36	95	. .	69
5005-H34	160	140	8	. .	41	95	. .	69
5005-H36	180	165	6	. .	46	105	. .	69
5005-H38	200	185	5	. .	51	110	. .	69
5050-O	145	55	24	. .	36	105	85	69
5050-H32	170	145	9	. .	46	115	90	69
5050-H34	190	165	8	. .	53	125	90	69
5050-H36	205	180	7	. .	58	130	95	69
5050-H38	220	200	6	. .	63	140	95	69
5052-O	195	90	25	27	47	125	110	70
5052-H32	230	195	12	16	60	140	115	70
5052-H34	260	215	10	12	68	145	125	70
5052-H36	275	240	8	9	73	160	130	70
5052-H38	290	255	7	7	77	165	140	70
5056-O	290	150	. .	32	65	180	140	71
5056-H18	435	405	. .	9	105	235	150	71
5056-H38	415	345	. .	13	100	220	150	71

For all numbered footnotes, see page IV-32.

Table 6M
TYPICAL MECHANICAL PROPERTIES (Continued) ① ②

ALLOY AND TEMPER	TENSION				HARDNESS	SHEAR	FATIGUE	MODULUS
	STRENGTH MPa		ELONGATION percent.		BRINNELL NUMBER	ULTIMATE SHEARING STRENGTH	ENDURANCE ③ LIMIT	MODULUS ④ OF ELASTICITY
	ULTIMATE	YIELD	1.60 mm Thick Specimen	12.5 mm Diameter Specimen	500 kg load 10 mm ball	MPa	MPa	MPa × 10^3
5083-O	290	145	. .	20	. .	170	. .	71
5083-H116 ⑪	315	230	. .	14	. .	. .	160	71
5083-H321	315	230	. .	14	. .	. .	160	71
5086-O	260	115	22	. .	. .	165	. .	71
5086-H32	290	205	12	. .	. .	. .	. .	71
5086-H116 ⑪	290	205	12	. .	. .	. .	. .	71
5086-H34	325	255	10	. .	. .	185	. .	71
5086-H112	270	130	14	. .	. .	. .	. .	71
5154-O	240	115	27	. .	58	150	115	70
5154-H32	270	205	15	. .	67	150	125	70
5154-H34	290	230	13	. .	73	165	130	70
5154-H36	310	250	12	. .	78	180	140	70
5154-H38	330	270	10	. .	80	195	145	70
5154-H112	240	115	25	. .	63	. .	115	70
5252-H25	235	170	11	. .	68	145	. .	69
5252-H38, H28	285	240	5	. .	75	160	. .	69
5254-O	240	115	27	. .	58	150	115	70
5254-H32	270	205	15	. .	67	150	125	70
5254-H34	290	230	13	. .	73	165	130	70
5254-H36	310	250	12	. .	78	180	140	70
5254-H38	330	270	10	. .	80	195	145	70
5254-H112	240	115	25	. .	63	. .	115	70
5454-O	250	115	22	. .	62	160	. .	70
5454-H32	275	205	10	. .	73	165	. .	70
5454-H34	305	240	10	. .	81	180	. .	70
5454-H111	260	180	14	. .	70	160	. .	70
5454-H112	250	125	18	. .	62	160	. .	70
5456-O	310	160	. .	22	. .	. .	. .	71
5456-H112	310	165	. .	20	. .	. .	. .	71
5456-H321, H116	350	255	. .	14	90	205	. .	71
5457-O	130	50	22	. .	32	85	. .	69
5457-H25	180	160	12	. .	48	110	. .	69
5457-H38, H28	205	185	6	. .	55	125	. .	69
5652-O	195	90	25	27	47	125	110	70
5652-H32	230	195	12	16	60	140	115	70
5652-H34	260	215	10	12	68	145	125	70
5652-H36	275	240	8	9	73	160	130	70
5652-H38	290	255	7	7	77	165	140	70
5657-H25	160	140	12	. .	40	95	. .	69
5657-H38, H28	195	165	7	. .	50	105	. .	69
6061-O	125	55	25	27	30	85	60	69
6061-T4, T451	240	145	22	22	65	165	95	69
6061-T6, T651	310	275	12	15	95	205	95	69
Alclad 6061-O	115	50	25	. .	. .	75	. .	69
Alclad 6061-T4, T451	230	130	22	. .	. .	150	. .	69
Alclad 6061-T6, T651	290	255	12	. .	. .	185	. .	69
6063-O	90	50	. .	. .	25	70	55	69
6063-T1	150	90	20	. .	42	95	60	69
6063-T4	170	90	22	. .	. .	. .	. .	69
6063-T5	185	145	12	. .	60	115	70	69
6063-T6	240	215	12	. .	73	150	70	69
6063-T83	255	240	9	. .	82	150	. .	69
6063-T831	205	185	10	. .	70	125	. .	69
6063-T832	290	270	12	. .	95	185	. .	69

For all numbered footnotes, see page IV-32.

Table 6M
TYPICAL MECHANICAL PROPERTIES (Continued) ① ②

ALLOY AND TEMPER	TENSION				HARDNESS	SHEAR	FATIGUE	MODULUS
	STRENGTH MPa		ELONGATION percent		BRINNELL NUMBER	ULTIMATE SHEARING STRENGTH	ENDURANCE ③ LIMIT	MODULUS ④ OF ELASTICITY
	ULTIMATE	YIELD	1.60 mm Thick Specimen	12.5 mm Diameter Specimen	500 kg load 10 mm ball	MPa	MPa	MPa × 10^3
6066-O	150	85	. .	16	43	95	. .	69
6066-T4, T451	360	205	. .	16	90	200	. .	69
6066-T6. T651	395	360	. .	10	120	235	110	69
6070-T6	380	350	10	. .	. .	235	95	69
6101-H111	95	75	. .	. .	. .	. .	. .	69
6101-T6	220	195	15 ⑧	. .	71	140	. .	69
6262-T9	400	380	. .	9	120	240	90	69
6351-T4	250	150	20	. .	. .	. .	. .	69
6351-T6	310	285	14	. .	95	200	90	69
6463-T1	150	90	20	. .	42	95	70	69
6463-T5	185	145	12	. .	60	115	70	69
6463-T6	240	215	12	. .	74	150	70	69
7049-T73	515	450	. .	10	135	305	. .	72
7049-T7352	515	435	. .	9	135	295	. .	72
7050-T73510, T73511	495	435	. .	11	. .	. .	. .	72
7050-T7451 ⑩	525	470	. .	10	. .	305	. .	72
7050-T7651	550	490	. .	10	. .	325	. .	72
7075-O	230	105	17	14	60	150	. .	72
7075-T6, T651	570	505	11	9	150	330	160	72
Alclad 7075-O	220	95	17	. .	. .	150	. .	72
Alclad 7075-T6, T651	525	460	11	. .	. .	315	. .	72
7175-T74	525	455	. .	10	135	290	160	72
7178-O	230	105	15	14	. .	. .	. .	72
7178-T6, T651	605	540	10	9	. .	. .	. .	72
7178-T76, T7651	570	505	. .	9	. .	. .	. .	71
Alclad 7178-O	220	95	16	. .	. .	. .	. .	72
Alclad 7178-T6, T651	560	460	10	. .	. .	. .	. .	72
7475-T61	565	490	11	. .	. .	. .	. .	70
7475-T651	585	510	. .	13	. .	. .	. .	72
7475-T7351	495	420	. .	13	. .	. .	. .	72
7475-T761	515	450	12	. .	. .	. .	. .	70
7475-T7651	530	460	. .	12	. .	. .	. .	72
Alclad 7475-T61	515	455	11	. .	. .	. .	. .	70
Alclad 7475-T761	490	420	12	. .	. .	. .	. .	70
8176-H24	160	95	15	. .	. .	70	. .	69

① The mechanical property limits are listed by major product in the "Standards Section" of this manual.

② The indicated typical mechanical properties for all except 0 temper material are higher than the specified minimum properties. For 0 temper products typical ultimate and yield values are slightly lower than specified (maximum) values.

③ Based on 500,000,000 cycles of completely reversed stress using the R.R. Moore type of machine and specimen.

④ Average of tension and compression moduli. Compression modulus is about 2% greater than tension modulus.

⑤ 1350-O wire will have an elongation of approximately 23% in 10 inches.

⑥ 1350-H19 wire will have an elongation of approximately 1½% in 10 inches.

⑦ Tempers T361 and T861 were formerly designated T36 and T86, respectively.

⑧ Based on ¼ in. thick specimen.

⑨ Based on 10^7 cycles using flexural type testing of sheet specimens.

⑩ T7451, although not previously registered, has appeared in literature and in some specifications as T73651.

⑪ 5xxx products in the -H116 and -H32X tempers have similar mechanical properties; however, production methods and testing requirements differ, and these tempers are not interchangeable. The -H116 temper is typically used in marine and other applications requiring demonstrations of exfoliation resistance.

Table 7
TYPICAL PHYSICAL PROPERTIES—THERMAL AND ELECTRICAL

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size. These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

ALLOY	AVERAGE ① COEFFICIENT OF THERMAL EXPANSION	MELTING RANGE ② ③ APPROX.	TEMPER	THERMAL CONDUCTIVITY AT 77°F	ELECTRICAL CONDUCTIVITY AT 68°F Percent of International Annealed Copper Standard		ELECTRICAL RESISTIVITY AT 68°F
	68° TO 212°F per °F	°F		English Units ④	Equal Volume	Equal Weight	Ohm—Cir. Mil/Foot
1060	13.1	1195–1215	O	1625	62	204	17
			H18	1600	61	201	17
1100	13.1	1190–1215	O	1540	59	194	18
			H18	1510	57	187	18
1350	13.2	1195–1215	All	1625	62	204	17
2011	12.7	1005–1190 ⑥	T3	1050	39	123	27
			T8	1190	45	142	23
2014	12.8	945–1180 ⑤	O	1340	50	159	21
			T4	930	34	108	31
			T6	1070	40	127	26
2017	13.1	955–1185 ⑤	O	1340	50	159	21
			T4	930	34	108	31
2018	12.4	945–1180 ⑥	T61	1070	40	127	26
2024	12.9	935–1180 ⑤	O	1340	50	160	21
			T3, T4, T361	840	30	96	35
			T6, T81, T861	1050	38	122	27
2025	12.6	970–1185 ⑤	T6	1070	40	128	26
2036	13.0	1030–1200 ⑥	T4	1100	41	135	25
2117	13.2	1030–1200 ⑥	T4	1070	40	130	26
2124	12.7	935–1180 ⑤	T851	1055	38	122	27
2218	12.4	940–1175 ⑤	T72	1070	40	126	26
2219	12.4	1010–1190 ⑤	O	1190	44	138	24
			T31, T37	780	28	88	37
			T6, T81, T87	840	30	94	35
2618	12.4	1020–1180	T6	1020	37	120	28
3003	12.9	1190–1210	O	1340	50	163	21
			H12	1130	42	137	25
			H14	1100	41	134	25
			H18	1070	40	130	26
3004	13.3	1165–1210	All	1130	42	137	25
3105	13.1	1175–1210	All	1190	45	148	23
4032	10.8	990–1060 ⑤	O	1070	40	132	26
			T6	960	35	116	30
4043	12.3	1065–1170	O	1130	42	140	25
4045	11.7	1065–1110	All	1190	45	151	23
4343	12.0	1070–1135	All	1250	47	158	25
5005	13.2	1170–1210	All	1390	52	172	20
5050	13.2	1155–1205	All	1340	50	165	21
5052	13.2	1125–1200	All	960	35	116	30
5056	13.4	1055–1180	O	810	29	98	36
			H38	750	27	91	38
5083	13.2	1095–1180	O	810	29	98	36
5086	13.2	1085–1185	All	870	31	104	33
5154	13.3	1100–1190	All	870	32	107	32
5252	13.2	1125–1200	All	960	35	116	30
5254	13.3	1100–1190	All	870	32	107	32
5356	13.4	1060–1175	O	810	29	98	36
5454	13.1	1115–1195	O	930	34	113	31
			H38	930	34	113	31
5456	13.3	1055–1180	O	810	29	98	36
5457	13.2	1165–1210	All	1220	46	153	23
5652	13.2	1125–1200	All	960	35	116	30
5657	13.2	1180–1215	All	1420	54	180	19

For all numbered footnotes, see page IV-34.

Table 7
TYPICAL PHYSICAL PROPERTIES—THERMAL AND ELECTRICAL (Continued)

ALLOY	AVERAGE ① COEFFICIENT OF THERMAL EXPANSION	MELTING RANGE ② ③ APPROX.	TEMPER	THERMAL CONDUCTIVITY AT 77°F	ELECTRICAL CONDUCTIVITY AT 68°F Percent of International Annealed Copper Standard		ELECTRICAL RESISTIVITY AT 68°F
	68° TO 212°F per °F	°F		English Units ④	Equal Volume	Equal Weight	Ohm—Cir. Mil/Foot
6005	13.0	1125–1210 ⑥	T1	1250	47	155	22
			T5	1310	49	161	21
6053	12.8	1070–1205 ⑥	O	1190	45	148	23
			T4	1070	40	132	26
			T6	1130	42	139	25
6061	13.1	1080–1205 ⑥	O	1250	47	155	22
			T4	1070	40	132	26
			T6	1160	43	142	24
6063	13.0	1140–1210	O	1510	58	191	18
			T1	1340	50	165	21
			T5	1450	55	181	19
			T6, T83	1390	53	175	20
6066	12.9	1045–1195 ⑤	O	1070	40	132	26
			T6	1020	37	122	28
6070	. .	1050–1200 ⑤	T6	1190	44	145	24
6101	13.0	1150–1210	T6	1510	57	188	18
			T61	1540	59	194	18
			T63	1510	58	191	18
			T64	1570	60	198	17
			T65	1510	58	191	18
6105	13.0	1110–1200 ⑥	T1	1220	46	151	23
			T5	1340	50	165	21
6151	12.9	1090–1200 ⑥	O	1420	54	178	19
			T4	1130	42	138	25
			T6	1190	45	148	23
6201	13.0	1125–1210 ⑥	T81	1420	54	180	19
6262	13.0	1080–1205 ⑥	T9	1190	44	145	24
6351	13.0	1030–1200	T6	1220	46	151	23
6463	13.0	1140–1210	T1	1340	50	165	21
			T5	1450	55	181	19
			T6	1390	53	175	20
6951	13.0	1140–1210	O	1480	56	186	19
			T6	1370	52	172	20
7049	13.0	890–1175	T73	1070	40	132	26
7050	12.8	910–1165	T74 ⑧	1090	41	135	25
7072	13.1	1185–1215	O	1540	59	193	18
7075	13.1	890–1175 ⑦	T6	900	33	105	31
7175	13.0	890–1175 ⑦	T74	1080	39	124	26
7178	13.0	890–1165 ⑦	T6	870	31	98	33
7475	12.9	890–1175	T61, T651	960	35	116	30
			T76, T761	1020	40	132	26
			T7351	1130	42	139	25
8017	13.1	1190–1215	H12, H22	. .	59	193	18
			H212	. .	61	200	17
8030	13.1	1190–1215	H221	1600	61	201	17
8176	13.1	1190–1215	H24		61	201	17

① Coefficient to be multiplied by 10^{-6}. Example: $12.2 \times 10^{-6} = 0.0000122$.

② Melting ranges shown apply to wrought products of ¼ inch thickness or greater.

③ Based on typical composition of the indicated alloys.

④ English units = btu-in./ft^2hr°F.

⑤ Eutectic melting is not eliminated by homogenization.

⑥ Eutectic melting can be completely eliminated by homogenization.

⑦ Homogenization may raise eutectic melting temperature 20–40°F but usually does not eliminate eutectic melting.

⑧ Although not formerly registered, the literature and some specifications have used T736 as the designation for this temper.

Table 7M
TYPICAL PHYSICAL PROPERTIES—THERMAL AND ELECTRICAL

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size. These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

ALLOY	AVERAGE ① COEFFICIENT OF THERMAL EXPANSION	MELTING RANGE ② ③ APPROX.	TEMPER	THERMAL CONDUCTIVITY AT 25°C	ELECTRICAL CONDUCTIVITY AT 20°C MS/m		ELECTRICAL RESISTIVITY AT 20°C
	20° TO 100°C per °C	°C		W/m-K	Equal Volume	Equal Mass	Ohm—mm^2/m
1060	23.6	645–655	O	234	36	118	0.028
			H18	230	35	117	0.029
1100	23.6	640–655	O	222	34	113	0.029
			H18	218	33	108	0.030
1350	23.6	645–655	All	234	36	118	0.028
2011	22.9	540–645 ⑤	T3	151	23	71	0.043
			T8	172	26	82	0.038
2014	23.0	505–635 ④	O	193	29	92	0.034
			T4	134	20	63	0.050
			T6	155	23	74	0.043
2017	23.6	510–640 ④	O	193	29	92	0.034
			T4	134	20	63	0.050
2018	22.3	505–640 ⑤	T61	155	23	74	0.043
2024	23.2	500–635 ④	O	193	29	93	0.034
			T3, T4, T361	121	17	56	0.059
			T6, T81, T861	151	22	71	0.045
2025	22.7	520–640 ④	T6	155	23	74	0.043
2036	23.4	555–650 ⑤	T4	159	24	78	0.042
2117	23.8	550–650 ⑤	T4	155	23	75	0.043
2124	22.9	500–635 ④	T851	152	22	71	0.045
2218	22.3	505–635 ④	T72	155	23	73	0.043
2219	22.3	545–645 ④	O	172	26	80	0.038
			T31, T37	113	16	57	0.062
			T6, T81, T87	121	17	58	0.059
2618	22.3	550–640	T6	146	21	70	0.048
3003	23.2	640–655	O	193	29	92	0.034
			H12	163	24	78	0.042
			H14	159	24	78	0.042
			H18	155	23	74	0.043
3004	23.9	630–655	All	163	24	79	0.042
3105	23.6	635–655	All	172	26	86	0.038
4032	19.4	530–570 ④	O	155	23	77	0.043
			T6	138	20	67	0.050
4043	22.0	575–630	O	163	24	81	0.041
4045	21.1	575–600	All	171	26	88	0.038
4343	21.6	575–615	All	180	27	92	0.037
5005	23.8	630–655	All	201	30	100	0.033
5050	23.8	625–650	All	193	29	96	0.034
5052	23.8	605–650	All	138	20	67	0.050
5056	24.1	565–640	O	117	17	57	0.059
			H38	109	16	53	0.062
5083	23.8	580–640	O	117	17	57	0.059
5086	23.8	585–640	All	126	18	60	0.056
5154	23.9	590–645	All	126	19	62	0.053
5252	23.8	605–650	All	138	20	67	0.050
5254	23.9	590–645	All	126	19	62	0.053
5356	24.1	575–635	O	117	17	57	0.059
5454	23.6	600–645	O	134	20	66	0.050
			H38	134	20	66	0.050
5456	23.9	570–640	O	117	17	57	0.059
5457	23.8	630–655	All	176	27	89	0.037
5652	23.8	605–650	All	138	20	69	0.050
5657	23.8	635–655	All	205	31	104	0.032

For all numbered footnotes, see page IV-36.

Table 7M
TYPICAL PHYSICAL PROPERTIES—THERMAL AND ELECTRICAL (Continued)

ALLOY	AVERAGE ① COEFFICIENT OF THERMAL EXPANSION	MELTING RANGE ② ③ APPROX.	TEMPER	THERMAL CONDUCTIVITY AT 25°C	ELECTRICAL CONDUCTIVITY AT 20°C MS/m		ELECTRICAL RESISTIVITY AT 20°C
	20° TO 100°C per °C	°C		W/m-K	Equal Volume	Equal Mass	Ohm—mm^2/m
6005	23.6	605–655 ⑤	T1	180	27	90	0.037
			T5	188	28	93	0.036
6053	23.0	575–650 ⑤	O	172	26	86	0.038
			T4	155	23	77	0.042
			T6	167	24	81	0.041
6061	23.6	580–650 ⑤	O	180	27	90	0.037
			T4	155	23	77	0.043
			T6	167	25	82	0.040
6063	23.4	615–655	O	218	34	111	0.029
			T1	193	29	96	0.034
			T5	209	32	105	0.031
			T6, T83	201	31	102	0.032
6066	23.2	560–645 ④	O	155	23	77	0.043
			T6	146	21	71	0.048
6070	. .	565–650 ④	T6	172	26	84	0.038
6101	23.4	620–655	T6	218	33	109	0.030
			T61	222	34	113	0.029
			T63	218	34	111	0.029
			T64	226	35	115	0.029
			T65	218	34	111	0.029
6105	23.4	600–650 ⑥	T1	176	27	88	0.037
			T5	193	29	96	0.034
6151	23.2	590–650 ⑤	O	205	31	103	0.032
			T4	163	24	80	0.042
			T6	172	26	86	0.038
6201	23.4	610–655 ⑤	T81	205	31	104	0.032
6262	23.4	580–650 ⑤	T9	172	26	84	0.038
6351	23.4	555–650	T6	176	27	88	0.038
6463	23.4	615–655 ⑤	T1	193	29	96	0.034
			T5	209	32	105	0.031
			T6	201	31	102	0.032
6951	23.4	615–655	O	213	32	108	0.031
			T6	197	30	100	0.033
7049	23.4	475–635	T73	155	23	77	0.043
7050	23.0	490–630	T74 ⑦	157	24	78	0.042
7072	23.6	640–655	O	222	34	112	0.029
7075	23.6	475–635 ⑥	T6	130	19	61	0.053
7175	23.4	475–635 ⑥	T74	157	23	72	0.043
7178	23.4	475–630 ⑥	T6	126	18	57	0.056
7475	23.2	475–635	T61, T651	138	20	69	0.050
			T76, T761	146	23	77	0.043
			T7351	163	24	81	0.041
8017	23.6	645–655	H12, H22	. .	34	113	0.029
			H212	. .	35	117	0.029
8030	23.6	645–655	H221	230	35	117	0.029
8176	23.6	645–655	H24	230	35	117	0.029

① Coefficient to be multiplied by 10^{-6}. Example: $23.6 \times 10^{-6} = 0.0000236$.
② Melting ranges shown apply to wrought products of 6 mm thickness or greater.
③ Based on typical composition of the indicated alloys.
④ Eutectic melting is not eliminated by homogenization.
⑤ Eutectic melting can be completely eliminated by homogenization.
⑥ Homogenization may raise eutectic melting temperature 10–20°C but usually does not eliminate eutectic melting.
⑦ Although not formerly registered, the literature and some specifications have used T736 as the designation for this temper.
⑧ MS/m = 0.58 × % IACS.

Table 8
TYPICAL PHYSICAL PROPERTIES—DENSITY

Density and specific gravity are dependent upon composition, and variations are discernible from one cast to another for most alloys. The nominal values shown below should not be specified as engineering requirements but are used in calculating typical values for weight per unit length, weight per unit area, covering area, etc. The density values are derived from the metric and subsequently rounded. These values are not to be converted to the metric. X.XXX0 and X.XXX5 density values and X.XX0 and X.XX5 specific gravity values are limited to 99.35 percent or higher purity aluminum.

Alloy	Density (lbs/cu. in.)	Specific Gravity
1050	.0975	2.705
1060	.0975	2.705
1100	.098	2.71
1145	.0975	2.700
1175	.0975	2.700
1200	.098	2.70
1230	.098	2.70
1235	.0975	2.705
1345	.0975	2.705
1350	.0975	2.705
2011	.102	2.83
2014	.101	2.80
2017	.101	2.79
2018	.102	2.82
2024	.100	2.78
2025	.101	2.81
2036	.100	2.75
2117	.099	2.75
2124	.100	2.78
2218	.101	2.81
2219	.103	2.84
2618	.100	2.76
3003	.099	2.73
3004	.098	2.72
3005	.098	2.73
3105	.098	2.72
4032	.097	2.68
4043	.097	2.69
4045	.096	2.67
4047	.096	2.66
4145	.099	2.74
4343	.097	2.68
4643	.097	2.69
5005	.098	2.70
5050	.097	2.69
5052	.097	2.68
5056	.095	2.64
5083	.096	2.66
5086	.096	2.66
5154	.096	2.66
5183	.096	2.66
5252	.096	2.67
5254	.096	2.66
5356	.096	2.64
5454	.097	2.69
5456	.096	2.66
5457	.097	2.69
5554	.097	2.69
5556	.096	2.66
5652	.097	2.67
5654	.096	2.66
5657	.097	2.69
6003	.097	2.70
6005	.097	2.70
6053	.097	2.69
6061	.098	2.70
6063	.097	2.70
6066	.098	2.72
6070	.098	2.71
6101	.097	2.70
6105	.097	2.69
6151	.098	2.71
6162	.097	2.70
6201	.097	2.69
6262	.098	2.72
6351	.098	2.71
6463	.097	2.69
6951	.098	2.70
7005	.100	2.78
7008	.100	2.78
7049	.103	2.84
7050	.102	2.83
7072	.098	2.72
7075	.101	2.81
7175	.101	2.80
7178	.102	2.83
7475	.101	2.81
8017	.098	2.71
8030	.098	2.71
8176	.098	2.71
8177	.098	2.70

Table 9
TYPICAL TENSILE PROPERTIES AT VARIOUS TEMPERATURES ①

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size. These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

ALLOY AND TEMP	TEMP.	TENSILE STRENGTH, ksi		ELONGATION IN 2 IN., PERCENT
	°F	ULTIMATE	YIELD ②	
1100-O	–320	25	6	50
	–112	15	5.5	43
	–18	14	5	40
	75	13	5	40
	212	10	4.6	45
	300	8	4.2	55
	400	6	3.5	65
	500	4	2.6	75
	600	2.9	2	80
	700	2.1	1.6	85
1100-H14	–320	30	20	45
	–112	20	18	24
	–18	19	17	20
	75	18	17	20
	212	16	15	20
	300	14	12	23
	400	10	7.5	26
	500	4	2.6	75
	600	2.9	2	80
	700	2.1	1.6	85
1100-H18	–320	34	26	30
	–112	26	23	16
	–118	25	23	15
	75	24	22	15
	212	21	19	15
	300	18	14	20
	400	6	3.5	65
	500	4	2.6	75
	600	2.9	2	80
	700	2.1	1.6	85
2011-T3	75	55	43	15
	212	47	34	16
	300	28	19	25
	400	16	11	35
	500	6.5	3.8	45
	600	3.1	1.8	90
	700	2.3	1.4	125
2014-T6, T651	–320	84	72	14
	–112	74	65	13
	–18	72	62	13
	75	70	60	13
	212	63	57	15
	300	40	35	20
	400	16	13	38
	500	9.5	7.5	52
	600	6.5	5	65
	700	4.3	3.5	72
2017-T4, T451	–320	80	53	28
	–112	65	42	24
	–18	64	41	23
	75	62	40	22
	212	57	39	18
	300	40	30	15
	400	16	13	35
	500	9	7.5	45
	600	6	5	65
	700	4.3	3.5	70
2024-T3 (Sheet)	–320	85	62	18
	–112	73	52	17
	–18	72	51	17
	75	70	50	17
	212	66	48	16
	300	55	45	11
	400	27	20	23
	500	11	9	55
	600	7.5	6	75
	700	5	4	100
2024-T4, T351 (plate)	–320	84	61	19
	–112	71	49	19
	–18	69	47	19
	75	68	47	19
	212	63	45	19
	300	45	36	17
	400	26	19	27
	500	11	9	55
	600	7.5	6	75
	700	5	4	100
2024-T6, T651	–320	84	68	11
	–112	72	59	10
	–18	70	58	10
	75	69	57	10
	212	65	54	10
	300	45	36	17
	400	26	19	27
	500	11	9	55
	600	7.5	6	75
	700	5	4	100
2024-T81, T851	–320	85	78	8
	–112	74	69	7
	–18	73	68	7
	75	70	65	7
	212	66	62	8
	300	55	49	11
	400	27	20	23
	500	11	9	55
	600	7.5	6	75
	700	5	4	100
2024-T861	–320	92	85	5
	–112	81	77	5
	–18	78	74	5
	75	75	71	5
	212	70	67	6
	300	54	48	11
	400	21	17	28
	500	11	9	55
	600	7.5	6	75
	700	5	4	100
2117-T4	–320	56	33	30
	–112	45	25	29
	–18	44	24	28
	75	43	24	27
	212	36	21	16
	300	30	17	20
	400	16	12	35
	500	7.5	5.5	55
	600	4.7	3.3	80
	700	2.9	2	110

For all numbered footnotes, see page IV-42.

Table 9
TYPICAL TENSILE PROPERTIES AT VARIOUS TEMPERATURES ① (Continued)

ALLOY AND TEMP	TEMP.	TENSILE STRENGTH, ksi		ELONGATION IN 2 IN., PERCENT
	°F	ULTIMATE	YIELD ②	
2124-T851	–452	102	90	10
	–320	86	79	9
	–112	76	71	8
	–18	73	68	8
	75	70	64	9
	212	66	61	9
	300	54	49	13
	400	27	20	28
	500	11	8	60
	600	7.5	6	75
	700	5.5	4.1	100
2218-T61	–320	72	52	15
	–112	61	45	14
	–18	59	44	13
	75	59	44	13
	212	56	42	15
	300	41	35	17
	400	22	16	30
	500	10	6	70
	600	5.5	3	85
	700	4	2.5	100
2219-T62	–320	73	49	16
	–112	63	44	13
	–18	60	42	12
	75	58	40	12
	212	54	37	14
	300	45	33	17
	400	34	25	20
	500	27	20	21
	600	10	8	40
	700	4.4	3.7	75
2219-T81, T851	–320	83	61	15
	–112	71	54	13
	–18	69	52	12
	75	66	50	12
	212	60	47	15
	300	49	40	17
	400	36	29	20
	500	29	23	21
	600	7	6	55
	700	4.4	3.7	75
2618-T61	–320	78	61	12
	–12	67	55	11
	–18	64	54	10
	75	64	54	10
	212	62	54	10
	300	50	44	14
	400	32	26	24
	500	13	9	50
	600	7.5	4.5	80
	700	5	3.5	120
3003-O	–320	33	8.5	46
	–112	20	7	42
	–18	17	6.5	41
	75	16	6	40
	212	13	5.5	43
	300	11	5	47
	400	8.5	4.3	60
	500	6	3.4	65
	600	4	2.4	70
	700	2.8	1.8	70
3003-H14	–320	35	25	30
	–112	24	22	18
	–18	22	21	16
	75	22	21	16
	212	21	19	16
	300	18	16	16
	400	14	9	20
	500	7.5	4	60
	600	4	2.4	70
	700	2.8	1.8	70
3003-H18	–320	41	33	23
	–112	32	29	11
	–18	30	28	10
	75	29	27	10
	212	26	21	10
	300	23	16	11
	400	14	9	18
	500	7.5	4	60
	600	4	2.4	70
	700	2.8	1.8	70
3004-O	–320	42	13	38
	–112	28	11	30
	–18	26	10	26
	75	26	10	25
	212	26	10	25
	300	22	10	35
	400	14	9.5	55
	500	10	7.5	70
	600	7.5	5	80
	700	5	3	90
3004-H34	–320	52	34	26
	–112	38	30	16
	–18	36	29	13
	75	35	29	12
	212	34	29	13
	300	28	25	22
	400	21	15	35
	500	14	7.5	55
	600	7.5	5	80
	700	5	3	90
3004-H38	–320	58	43	20
	–112	44	38	10
	–18	42	36	7
	75	41	36	6
	212	40	36	7
	300	31	27	15
	400	22	15	30
	500	12	7.5	50
	600	7.5	5	80
	700	5	3	90
4032-T6	–320	66	48	11
	–112	58	46	10
	–18	56	46	9
	75	55	46	9
	212	50	44	9
	300	37	33	9
	400	13	9	30
	500	8	5.5	50
	600	5	3.2	70
	700	3.4	2	90

For all numbered footnotes, see page IV-42.

Table 9
TYPICAL TENSILE PROPERTIES AT VARIOUS TEMPERATURES ① (Continued)

ALLOY AND TEMP	TEMP.	TENSILE STRENGTH, ksi		ELONGATION IN 2 IN., PERCENT
	°F	ULTIMATE	YIELD ②	
5050-O	–320	37	10	. .
	–112	22	8.5	. .
	–18	21	8	. .
	75	21	8	. .
	212	21	8	. .
	300	19	8	. .
	400	14	7.5	. .
	500	9	6	. .
	600	6	4.2	. .
	700	3.9	2.6	. .
5050-H34	–320	44	30	. .
	–112	30	25	. .
	–18	28	24	. .
	75	28	24	. .
	212	28	24	. .
	300	25	22	. .
	400	14	7.5	. .
	500	9	6	. .
	600	6	4.2	. .
	700	3.9	2.6	. .
5050-H38	–320	46	36	. .
	–112	34	30	. .
	–18	32	29	. .
	75	32	29	. .
	212	31	29	. .
	300	27	25	. .
	400	14	7.5	. .
	500	9	6	. .
	600	6	4.2	. .
	700	3.9	2.6	. .
5052-O	–320	44	16	46
	–112	29	13	35
	–18	28	13	32
	75	28	13	30
	212	28	13	36
	300	23	13	50
	400	17	11	60
	500	12	7.5	80
	600	7.5	5.5	110
	700	5	3.1	130
5052-H34	–320	55	36	28
	–112	40	32	21
	–18	38	31	18
	75	38	31	16
	212	38	31	18
	300	30	27	27
	400	24	15	45
	500	12	7.5	80
	600	7.5	5.5	110
	700	5	3.1	130
5052-H38	–320	60	44	25
	–112	44	38	18
	–18	42	37	15
	75	42	37	14
	212	40	36	16
	300	34	28	24
	400	25	15	45
	500	12	7.5	80
	600	7.5	5.5	110
	700	5	3.1	130
5083-O	–320	59	24	36
	–112	43	21	30
	–18	42	21	27
	75	42	21	25
	212	40	21	36
	300	31	19	50
	400	22	17	60
	500	17	11	80
	600	11	7.5	110
	700	6	4.2	130
5086-O	–320	55	19	46
	–112	39	17	35
	–18	38	17	32
	75	38	17	30
	212	38	17	36
	300	29	16	50
	400	22	15	60
	500	17	11	80
	600	11	7.5	110
	700	6	4.2	130
5154-O	–320	52	19	46
	–112	36	17	35
	–18	35	17	32
	75	35	17	30
	212	35	17	36
	300	29	16	50
	400	22	15	60
	500	17	11	80
	600	11	7.5	110
	700	6	4.2	130
5254-O	–320	52	19	46
	–112	36	17	35
	–18	35	17	32
	75	35	17	30
	212	35	17	36
	300	29	16	50
	400	22	15	60
	500	17	11	80
	600	11	7.5	110
	700	6	4.2	130
5454-O	–320	54	19	39
	–112	37	17	30
	–18	36	17	27
	75	36	17	25
	212	36	17	31
	300	29	16	50
	400	22	15	60
	500	17	11	80
	600	11	7.5	110
	700	6	4.2	130
5454-H32	–320	59	36	32
	–112	42	31	23
	–18	41	30	20
	75	40	30	18
	212	39	29	20
	300	32	26	37
	400	25	19	45
	500	17	11	80
	600	11	7.5	110
	700	6	4.2	130

For all numbered footnotes, see page IV-42.

Table 9
TYPICAL TENSILE PROPERTIES AT VARIOUS TEMPERATURES ① (Continued)

ALLOY AND TEMP	TEMP.	TENSILE STRENGTH, ksi		ELONGATION IN 2 IN., PERCENT
	°F	ULTIMATE	YIELD ②	
5454-H34	–320	63	41	30
	–112	46	36	21
	–18	44	35	18
	75	44	35	16
	212	43	34	18
	300	34	28	32
	400	26	19	45
	500	17	11	80
	600	11	7.5	110
	700	6	4.2	130
5456-O	–320	62	26	32
	–112	46	23	25
	–18	45	23	22
	75	45	23	20
	212	42	22	31
	300	31	20	50
	400	22	17	60
	500	17	11	80
	600	11	7.5	110
	700	6	4.2	130
5652-O	–320	44	16	46
	–112	29	13	35
	–18	28	13	32
	75	28	13	30
	212	28	13	30
	300	23	13	50
	400	17	11	60
	500	12	7.5	80
	600	7.5	5.5	110
	700	5	3.1	130
5652-H34	–320	55	36	28
	–112	40	32	21
	–18	38	31	18
	75	38	31	16
	212	38	31	18
	300	30	27	27
	400	24	15	45
	500	12	7.5	80
	600	7.5	5.5	110
	700	5	3.1	130
5652-H38	–320	60	44	25
	–112	44	38	18
	–18	42	37	15
	75	42	37	14
	212	40	36	16
	300	34	28	24
	400	25	15	45
	500	12	7.5	80
	600	7.5	5.5	110
	700	5	3.1	130
6053-T6, T651	75	37	32	13
	212	32	28	13
	300	25	24	13
	400	13	12	25
	500	5.5	4	70
	600	4	2.7	80
	700	2.9	2	90
6061-T6, T651	–320	60	47	22
	–112	49	42	18
	–18	47	41	17
	75	45	40	17
	212	42	38	18
	300	34	31	20
	400	19	15	28
	500	7.5	5	60
	600	4.6	2.7	85
	700	3	1.8	95
6063-T1	–320	34	16	44
	–112	26	15	36
	–18	24	14	34
	75	22	13	33
	212	22	14	18
	300	21	15	20
	400	9	6.5	40
	500	4.5	3.5	75
	600	3.2	2.5	80
	700	2.3	2	105
6063-T5	–320	37	24	28
	–112	29	22	24
	–18	28	22	23
	75	27	21	22
	212	24	20	18
	300	20	18	20
	400	9	6.5	40
	500	4.5	3.5	75
	600	3.2	2.5	80
	700	2.3	2	105
6063-T6	–320	47	36	24
	–112	38	33	20
	–18	36	32	19
	75	35	31	18
	212	31	28	15
	300	21	20	20
	400	9	6.5	40
	500	4.5	3.5	75
	600	3.3	2.5	80
	700	2.3	2	105
6101-T6	–320	43	33	24
	–112	36	30	20
	–18	34	29	19
	75	32	28	19
	212	28	25	20
	300	21	19	20
	400	10	7	40
	500	4.8	3.3	80
	600	3	2.3	100
	700	2.5	1.8	105
6151-T6	–320	57	50	20
	–112	50	46	17
	–18	49	45	17
	75	48	43	17
	212	43	40	17
	300	28	27	20
	400	14	12	30
	500	6.5	5	50
	600	5	3.9	43
	700	4	3.2	35

For all numbered footnotes, see page IV-42.

Table 9
TYPICAL TENSILE PROPERTIES AT VARIOUS TEMPERATURES ① (Continued)

ALLOY AND TEMP	TEMP.	TENSILE STRENGTH, ksi		ELONGATION IN 2 IN., PERCENT
	°F	ULTIMATE	YIELD ②	
6262-T651	–320	60	47	22
	–112	49	42	18
	–18	47	41	17
	75	45	40	17
	212	42	38	18
	300	34	31	20
6262-T9	–320	74	67	14
	–112	62	58	10
	–18	60	56	10
	75	58	55	10
	212	53	52	10
	300	38	37	14
	400	15	13	34
	500	8.5	6	48
	600	4.6	2.7	85
	700	3	1.8	95
7075-T6, T651	–320	102	92	9
	–112	90	79	11
	–18	86	75	11
	75	83	73	11
	212	70	65	14
	300	31	27	30
	400	16	13	55
	500	11	9	65
	600	8	6.5	70
	700	6	4.6	70
7075-T73, T7351	–320	92	72	14
	–112	79	67	14
	–18	76	65	13
	75	73	63	13
	212	63	58	15
	300	31	27	30
	400	16	13	55
	500	11	9	65
	600	8	6.5	70
	700	6	4.6	70
7175-T74	–320	106	98	13
	–112	90	83	14
	–18	87	80	16
	75	80	73	14
	212	72	69	17
	300	35	31	30
	400	18	13	65
7178-T6, T651	–320	106	94	5
	–112	94	84	8
	–18	91	81	9
	75	88	78	11
	212	73	68	14
	300	31	27	40
	400	15	12	70
	500	11	9	76
	600	8.5	7	80
	700	6.5	5.5	80
7178-T76, T7651	–320	106	89	10
	–112	91	78	10
	–18	88	76	10
	75	83	73	11
	212	69	64	17
	300	31	27	40
	400	15	12	70
	500	11	9	76
	600	8.5	7	80
	700	6.5	5.5	80
7475-T61 Sheet	–320	99	87	10
	–112	88	79	12
	–18	84	75	12
	75	80	72	12
	212	70	65	14
	300	30	26	28
	400	14	11	55
	500	9.5	7	70
	600	6.5	5.5	80
	700	5	3.8	85
7475-T761	–320	95	82	11
	–112	84	73	12
	–18	80	70	12
	75	76	67	12
	212	64	61	14
	300	30	26	38
	400	14	11	55
	500	9.5	7	70
	600	6.5	5.5	80
	700	5	3.8	85

① These data are based on a limited amount of testing and represent the lowest strength during 10,000 hours of exposure at testing temperature under no load; stress applied at 5,000 psi/min to yield strength and then at strain rate of 0.05 in./in./min to failure. Under some conditions of temperature and time, the application of heat will adversely affect certain other properties of some alloys.

② Offset equals 0.2 percent.

Table 9M
TYPICAL TENSILE PROPERTIES AT VARIOUS TEMPERATURES ①

The following typical properties are not guaranteed, since in most cases they are averages for various sizes, product forms and methods of manufacture and may not be exactly representative of any particular product or size. These data are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes.

ALLOY AND TEMPER	TEMP.	TENSILE STRENGTH, MPa		ELONGATION IN 50 MM PERCENT
	°C	ULTIMATE	YIELD ②	
1100-O	–195	170	41	50
	–80	105	38	43
	–30	95	34	40
	25	90	34	40
	100	70	32	45
	150	55	29	55
	205	41	24	65
	260	28	18	75
	315	20	14	80
	370	14	11	85
1100-H14	–195	205	140	45
	–80	140	125	24
	–30	130	115	20
	25	125	115	20
	100	110	105	20
	150	95	85	23
	205	70	50	26
	260	28	18	75
	315	20	14	80
	370	14	11	85
1100-H18	–195	235	180	30
	–80	180	160	16
	–30	170	160	15
	25	165	150	15
	100	145	130	15
	150	125	95	20
	205	41	24	65
	260	28	18	75
	315	20	14	80
	370	14	11	85
2011-T3	25	380	295	15
	100	325	235	16
	150	195	130	25
	205	110	75	35
	260	45	26	45
	315	21	12	90
	370	16	10	125
2014-T6, T651	–195	580	495	14
	–80	510	450	13
	–30	495	425	13
	25	485	415	13
	100	435	395	15
	150	275	240	20
	205	110	90	38
	260	65	50	52
	315	45	34	65
	370	30	24	72
2017-T4, T451	–195	550	365	28
	–80	450	290	24
	–30	440	285	23
	25	425	275	22
	100	395	270	18
	150	275	205	15
	205	110	90	35
	260	60	50	45
	315	41	34	65
	370	30	24	70

ALLOY AND TEMPER	TEMP.	TENSILE STRENGTH, MPa		ELONGATION IN 50 MM PERCENT
	°C	ULTIMATE	YIELD ②	
2024-T3 (Sheet)	–195	585	425	18
	–80	505	360	17
	–30	495	350	17
	25	485	345	17
	100	455	330	16
	150	380	310	11
	205	185	140	23
	260	75	60	55
	315	50	41	75
	370	34	28	100
2024-T4, T351 (plate)	–195	580	420	19
	–80	490	340	19
	–30	475	325	19
	25	470	325	19
	100	435	310	19
	150	310	250	17
	205	180	130	27
	260	75	60	55
	315	50	41	75
	370	34	28	100
2024-T6, T651	–195	580	470	11
	–80	495	405	10
	–30	485	400	10
	25	475	395	10
	100	450	370	10
	150	310	250	17
	205	180	130	27
	260	75	60	55
	315	50	41	75
	370	34	28	100
2024-T81, T851	–195	585	540	8
	–80	510	475	7
	–30	505	470	7
	25	485	450	7
	100	455	425	8
	150	380	340	11
	205	185	140	23
	260	75	60	55
	315	50	41	75
	370	34	28	100
2024-T861	–195	635	585	5
	–80	560	530	5
	–30	540	510	5
	25	515	490	5
	100	485	460	6
	150	370	330	11
	205	145	115	28
	260	75	60	55
	315	50	41	75
	370	34	28	100
2117-T4	–195	385	230	30
	–80	310	170	29
	–30	305	165	28
	25	295	165	27
	100	250	145	16
	150	205	115	20
	205	110	85	35
	260	50	38	55
	315	32	23	80
	370	20	14	110

For all numbered footnotes, see page IV-47.

Table 9M
TYPICAL TENSILE PROPERTIES AT VARIOUS TEMPERATURES ① (Continued)

ALLOY AND TEMPER	TEMP.	TENSILE STRENGTH, MPa		ELONGATION IN 50 MM PERCENT
	°C	ULTIMATE	YIELD ②	
2124-T851	–268	705	620	10
	–195	595	545	9
	–80	525	490	8
	–30	505	470	8
	25	485	440	9
	100	455	420	9
	150	370	340	13
	205	185	140	28
	260	75	55	60
	315	50	41	75
	370	38	28	100
2218-T61	–195	495	360	15
	–80	420	310	14
	–30	405	305	13
	25	405	305	13
	100	385	290	15
	150	285	240	17
	205	150	110	30
	260	70	41	70
	315	38	21	85
	370	28	17	100
2219-T62	–195	505	340	16
	–80	435	305	13
	–30	415	290	12
	25	400	275	12
	100	370	255	14
	150	310	230	17
	205	235	170	20
	260	185	140	21
	315	70	55	40
	370	30	26	75
2219-T81, T851	–195	570	420	15
	–80	490	370	13
	–30	475	360	12
	25	455	345	12
	100	415	325	15
	150	340	275	17
	205	250	200	20
	160	200	160	21
	315	48	41	55
	370	30	26	75
2618-T61	–195	540	420	12
	–80	460	380	11
	–30	440	370	10
	25	440	370	10
	100	425	370	10
	150	345	305	14
	205	220	180	24
	260	90	60	50
	315	50	31	80
	370	34	24	120
3003-O	–195	230	60	46
	–80	140	50	42
	–30	115	45	41
	25	110	41	40
	100	90	38	43
	150	75	34	47
	205	60	30	60
	260	41	23	65
	315	28	17	70
	370	19	12	70
3003-H14	–195	240	170	30
	–80	165	150	18
	–30	150	145	16
	25	150	145	16
	100	145	130	16
	150	125	110	16
	205	95	60	20
	260	50	28	60
	315	28	17	70
	370	19	12	70
3003-H18	–195	285	230	23
	–80	220	200	11
	–30	205	195	10
	25	200	185	10
	100	180	145	10
	150	160	110	11
	205	95	60	18
	260	50	28	60
	315	28	17	70
	370	19	12	70
3004-O	–195	290	90	38
	–80	195	75	30
	–30	180	70	26
	25	180	70	25
	100	180	70	25
	150	150	70	35
	205	95	65	55
	260	70	50	70
	315	50	34	80
	370	34	21	90
3004-H34	–195	360	235	26
	–80	260	205	16
	–30	250	200	13
	25	240	200	12
	100	235	200	13
	150	195	170	22
	205	145	105	35
	260	95	50	55
	315	50	34	80
	370	34	21	90
3004-H38	–195	400	295	20
	–80	305	260	10
	–30	290	250	7
	25	285	250	6
	100	275	250	7
	150	215	185	15
	205	150	105	30
	260	85	50	50
	315	50	34	80
	370	34	21	90
4032-T6	–195	455	330	11
	–80	400	315	10
	–30	385	315	9
	25	380	315	9
	100	345	305	9
	150	255	230	9
	205	90	60	30
	260	55	38	50
	315	34	22	70
	370	23	14	90

For all numbered footnotes, see page IV-47.

Table 9M
TYPICAL TENSILE PROPERTIES AT VARIOUS TEMPERATURES ① (Continued)

ALLOY AND TEMPER	TEMP.	TENSILE STRENGTH, MPa		ELONGATION IN 50 MM PERCENT	ALLOY AND TEMPER	TEMP.	TENSILE STRENGTH, MPa		ELONGATION IN 50 MM PERCENT
	°C	ULTIMATE	YIELD ②			°C	ULTIMATE	YIELD ②	
5050-O	–195	255	70	. .	5083-O	–195	405	165	36
	–80	150	60	. .		–80	295	145	30
	–30	145	55	. .		–30	290	145	27
	25	145	55	. .		25	290	145	25
	100	145	55	. .		100	275	145	36
	150	130	55	. .		150	215	130	50
	205	95	50	. .		205	150	115	60
	260	60	41	. .		260	115	75	80
	315	41	29	. .		315	75	50	110
	370	27	18	. .		370	41	29	130
5050-H34	–195	305	205	. .	5086-O	–195	380	130	46
	–80	205	170	. .		–80	270	115	35
	–30	195	165	. .		–30	260	115	32
	25	195	165	. .		25	260	115	30
	100	195	165	. .		100	260	115	36
	150	170	150	. .		150	200	110	50
	205	95	50	. .		205	150	105	60
	260	60	41	. .		260	115	75	80
	315	41	29	. .		315	75	50	110
	370	27	18	. .		370	41	29	130
5050-H38	–195	315	250	. .	5154-O	–195	360	130	46
	–80	235	205	. .		–80	250	115	35
	–30	220	200	. .		–30	240	115	32
	25	220	200	. .		25	240	115	30
	100	215	200	. .		100	240	115	36
	150	185	170	. .		150	200	110	50
	205	95	50	. .		205	150	105	60
	260	60	41	. .		260	115	75	80
	315	41	29	. .		315	75	50	110
	370	27	18	. .		370	41	29	130
5052-O	–195	305	110	46	5254-O	–195	360	130	46
	–80	200	90	35		–80	250	115	35
	–30	195	90	32		–30	240	115	32
	25	195	90	30		25	240	115	30
	100	195	90	36		100	240	115	36
	150	160	90	50		150	200	110	50
	205	115	75	60		205	150	105	60
	260	85	50	80		260	115	75	80
	315	50	38	110		315	75	50	110
	370	34	21	130		370	41	29	130
5052-H34	–195	380	250	28	5454-O	–195	370	130	39
	–80	275	220	21		–80	255	115	30
	–30	260	215	18		–30	250	115	27
	25	260	215	16		25	250	115	25
	100	260	215	18		100	250	115	31
	150	205	185	27		150	200	110	50
	205	165	105	45		205	150	105	60
	260	85	50	80		260	115	75	80
	315	50	38	110		315	75	50	110
	370	34	21	130		370	41	29	130
5052-H38	–195	415	305	25	5454-H32	–195	405	250	32
	–80	305	260	18		–80	290	215	23
	–30	290	255	15		–30	285	205	20
	25	290	255	14		25	275	205	18
	100	275	250	16		100	270	200	20
	150	235	195	24		150	220	180	37
	205	170	105	45		205	170	130	45
	260	85	50	80		260	115	75	80
	315	50	38	110		315	75	50	110
	370	34	21	130		370	41	29	130

For all numbered footnotes, see page IV-47.

Table 9M
TYPICAL TENSILE PROPERTIES AT VARIOUS TEMPERATURES ① (Continued)

ALLOY AND TEMPER	TEMP.	TENSILE STRENGTH, MPa		ELONGATION IN 50 MM PERCENT
	°C	ULTIMATE	YIELD ②	
5454-H34	–195	435	285	30
	–80	315	250	21
	–30	305	240	18
	25	305	240	16
	100	295	235	18
	150	235	195	32
	205	180	130	45
	260	115	75	80
	315	75	50	110
	370	41	29	130
5456-O	–195	425	180	32
	–80	315	160	25
	–30	310	160	22
	25	310	160	20
	100	290	150	31
	150	215	140	50
	205	150	115	60
	260	115	75	80
	315	75	50	110
	370	41	29	130
5652-O	–195	305	110	46
	–80	200	90	35
	–30	195	90	32
	25	195	90	30
	100	195	90	30
	150	160	90	50
	205	115	75	60
	260	85	50	80
	315	50	38	110
	370	34	21	130
5652-H34	–195	380	250	28
	–80	275	220	21
	–30	260	215	18
	25	260	215	16
	100	260	215	18
	150	205	185	27
	205	165	105	45
	260	85	50	80
	315	50	38	110
	370	34	21	130
5652-H38	–195	415	305	25
	–80	305	260	18
	–30	290	255	15
	25	290	255	14
	100	275	250	16
	150	235	195	24
	205	170	105	45
	260	85	50	80
	315	50	38	110
	370	34	21	130
6053-T6, T651	25	255	220	13
	100	220	195	13
	150	170	165	13
	205	90	85	25
	260	38	28	70
	315	28	19	80
	370	20	14	90
6061-T6, T651	–195	415	325	22
	–80	340	290	18
	–30	325	285	17
	25	310	275	17
	100	290	260	18
	150	235	215	20
	205	130	105	28
	260	50	34	60
	315	32	19	85
	370	21	12	95
6063-T1	–195	235	110	44
	–80	180	105	36
	–30	165	95	34
	25	150	90	33
	100	150	95	18
	150	145	105	20
	205	60	45	40
	260	31	24	75
	315	22	17	80
	370	16	14	105
6063-T5	–195	255	165	28
	–80	200	150	24
	–30	195	150	23
	25	185	145	22
	100	165	140	18
	150	140	125	20
	205	60	45	40
	260	31	24	75
	315	22	17	80
	370	16	14	105
6063-T6	–195	325	250	24
	–80	260	230	20
	–30	250	220	19
	25	240	215	18
	100	215	195	15
	150	145	140	20
	205	60	45	40
	260	31	24	75
	315	23	17	80
	370	16	14	105
6101-T6	–195	295	230	24
	–80	250	205	20
	–30	235	200	19
	25	220	195	19
	100	195	170	20
	150	145	130	20
	205	70	48	40
	260	33	23	80
	315	21	16	100
	370	17	12	105
6151-T6	–195	395	345	20
	–80	345	315	17
	–30	340	310	17
	25	330	295	17
	100	295	275	17
	150	195	185	20
	205	95	85	30
	260	45	34	50
	315	34	27	43
	370	28	22	35

For all numbered footnotes, see page IV-47.

Table 9M
TYPICAL TENSILE PROPERTIES AT VARIOUS TEMPERATURES ① (Continued)

ALLOY AND TEMPER	TEMP.	TENSILE STRENGTH, MPa		ELONGATION IN 50 MM PERCENT
	°C	ULTIMATE	YIELD ②	
6262-T651	–195	415	325	22
	–80	340	290	18
	–30	325	285	17
	25	310	275	17
	100	290	260	18
	150	235	215	20
6262-T9	–195	510	460	14
	–80	425	400	10
	–30	415	385	10
	25	400	380	10
	100	365	360	10
	150	260	255	14
	205	105	90	34
	260	60	41	48
	315	32	19	85
	370	21	12	95
7075-T6, T651	–195	705	635	9
	–80	620	545	11
	–30	595	515	11
	25	570	505	11
	100	485	450	14
	150	215	185	30
	205	110	90	55
	260	75	60	65
	315	55	45	70
	370	41	32	70
7075-T73, T7351	–195	635	495	14
	–80	545	460	14
	–30	525	450	13
	25	505	435	13
	100	435	400	15
	150	215	185	30
	205	110	90	55
	260	75	60	65
	315	55	45	70
	370	41	32	70
7175-T74	–195	730	675	13
	–80	620	570	14
	–30	600	550	16
	25	550	505	14
	100	495	475	17
	150	240	215	30
	205	125	90	65
7178-T6, T651	–195	730	650	5
	–80	650	580	8
	–30	625	560	9
	25	605	540	11
	100	505	470	14
	150	215	185	40
	205	105	85	70
	260	75	60	76
	315	60	48	80
	370	45	38	80
7178-T76, T7651	–195	730	615	10
	–80	625	540	10
	–30	605	525	10
	25	570	505	11
	100	475	440	17
	150	215	185	40
	205	105	85	70
	260	75	60	76
	315	60	48	80
	370	45	38	80
7475-T61 Sheet	–195	685	600	10
	–80	605	545	12
	–30	580	515	12
	25	550	495	12
	100	485	450	14
	150	205	180	28
	205	95	75	55
	260	65	50	70
	315	45	38	80
	370	34	26	85
7475-T761 Sheet	–195	655	565	11
	–80	580	505	12
	–30	550	485	12
	25	525	460	12
	100	440	420	14
	150	205	180	38
	205	95	75	55
	260	65	50	70
	315	45	38	80
	370	34	26	85

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① These data are based on a limited amount of testing and represent the lowest strength during 10,000 hours of exposure at testing temperature under no load; stress applied at 5,000 psi/min to yield strength and then at strain rate of 0.05 in./in./min to failure. Under some conditions of temperature and time, the application of heat will adversely affect certain other properties of some alloys.

② Offset equals 0.2 percent.

Aluminum Design Manual

PART V

Section Properties

V
Section Properties

TABLE OF CONTENTS

Table 1
NOMENCLATURE

Symbol	Property	Units
A	area	in^2
b	width	in.
C_w	warping constant	in^6
d	depth	in.
I	moment of inertia	in^4
J	torsion constant	in^4
r	radius of gyration	in.
r_0	polar radius of gyration about the shear center	in.
R	fillet radius	in.
R_b	mid-thickness radius of a pipe or tube	in.
S	section modulus	in^3
t	thickness	in.
t_f	flange thickness	in.
t_w	web thickness	in.
Wt	weight per unit length	lb/ft
x	location of the major axis	in.
x_0	x coordinate of shear center	in.
y	location of the minor axis	in.
y_0	y coordinate of shear center	in.

x and y subscripts denote the axis about which the property is taken.
The *x* axis is the major axis. The *y* axis is the minor axis.

Table 2
SECTION DESIGNATIONS

Section	Designation	Example	Description
Channels	CS *Depth* × *Wt*	CS 4 × 2.33	C shapes with flat flanges; includes Canadian Channels
Car and Shipbuilding Channels	CS *Depth* × *Wt*	CS 3 × 2.23	C shapes; some have flanges with a slope on the inner surface
American Standard Channels	C *Depth* × *Wt*	C 2 × 1.22	C shapes with flanges with a 1:6 slope on the inner surface
I-Beams	I *Depth* × *Wt*	I 12 × 11.7	I shapes with flat flanges; includes Canadian I-Beams
American Standard I-Beams	S *Depth* × *Wt*	S 10 × 12.1	I shapes with flanges with a 1:6 slope on the inner surface
Wide Flange Beams	WF *Nominal Depth* × *Wt*	WF 12 × 13.8	I shapes with a flange width approximately equal to the depth
Army-Navy Wide Flange Beams	WF(A-N) *Depth* × *Wt*	WF(A-N) 4 × 4.14	I shapes with flat flanges and a radius on the inside corner of the flanges
Angles	L *long leg* × *short leg* × *thickness*	L 3 × 2 × ¼	L shaped product with a fillet at the junction of the legs and radii on the inside tips of the legs
Square End Angles	LS *long leg* × *short leg* × *thickness*	LS 3 × 3 × ⅛	L shaped product with small radii at the corners
Tees	T *Depth* × *Width* × *Wt*	T 2.50 × 2.50 × 1.91	T shapes
Zees	Z *Depth* × *Width* × *Wt*	Z 4.00 × 3.19 × 4.32	Z shapes
Plates	PL *Thickness* × *Width*	PL 0.375 × 60	Rolled product with a rectangular cross section at least 0.25 in. thick
Rods	RD *Diameter*	RD 0.500	Solid product with a circular cross section at least 0.375 in. in diameter
Square Bars	SQ *Side dimension*	SQ 4	Solid product with a square cross section at least 0.375 in. on a side
Pipes	NPS *size* × SCH *schedule no.*	NPS 4 × SCH 40	Tube in standardized outside diameters and wall thicknesses
Round Tubes	*Outside diameter* OD × *wall thickness* WALL	4 OD × 0.125 WALL	Hollow product with a circular cross section
Rectangular Tubes	RT *short side* × *long side* × *wall thickness*	RT 4 × 6 × ¼	Hollow product with a rectangular cross section (including square tube)

Table 3
WEIGHTS PER SQUARE FOOT

The weight per square foot for an alloy with density of 0.100 lb/in^3 is shown for each thickness. The weights for other alloys can be calculated using the density given in Part IV Table 8. Commonly used thicknesses are shown **BOLD.**

Thickness (in.)			Thickness (in.)			Thickness (in.)		
Decimal	Fraction	Weight (lb/ft^2)	Decimal	Fraction	Weight (lb/ft^2)	Decimal	Fraction	Weight (lb/ft^2)
.006		0.086	.132		1.90	1.625	1 ⅝	23.40
.007		0.101	.140		2.02	1.750	1 ¾	25.20
.008		0.115	.150		2.16	1.875	1 ⅞	27.00
.009		0.130	**.160**		2.30	2.000	2	28.80
.010		0.144	.170		2.45	2.125	2 ⅛	30.60
.011		0.158	**.180**		2.59	2.250	2 ¼	32.40
.012		0.173	.1875	3/16	2.70	2.375	2 ⅜	34.20
.013		0.187	**.190**		2.74	2.500	2 ½	36.00
.014		0.202	.200		2.88	2.625	2 ⅝	37.80
.016	1/64	0.230	.212		3.05	2.750	2 ¾	39.60
.018		0.259	.224		3.23	2.875	2 ⅞	41.40
.019		0.274	.236		3.40	3.000	3	43.20
.020		0.288	**.250**	¼	3.60	3.250	3 ¼	46.80
.021		0.302	.266	17/64	3.83	3.500	3 ½	50.40
.022		0.317	.281	9/32	4.05	3.750	3 ¾	54.00
.024		0.346	.297	19/64	4.28	4.000	4	57.60
.025		0.360	**.313**	5/16	4.51	4.250	4 ¼	61.20
.026		0.374	.328	21/64	4.72	4.500	4 ½	64.80
.028		0.403	.344	11/32	4.95	4.750	4 ¾	68.40
.030		0.432	.359	23/64	5.17	5.000	5	72.00
.032		0.461	**.375**	⅜	5.40	5.250	5 ¼	75.60
.034		0.490	.391	25/64	5.63	5.500	5 ½	79.20
.036		0.518	.406	13/32	5.85	5.750	5 ¾	82.80
.038		0.547	.422	27/64	6.08	6.000	6	86.40
.040		0.576	.438	7/16	6.31			
.042		0.605	.453	29/64	6.52			
.045		0.648	.469	15/32	6.75			
.048		0.691	.484	31/64	6.97			
.050		0.720	**.500**	½	7.20			
.053		0.763	.531	17/32	7.65			
.056		0.806	.562	9/16	8.09			
.060		0.864	.594	19/32	8.55			
.063	1/16	0.907	**.625**	⅝	9.00			
.067		0.965	.656	21/32	9.45			
.071		1.02	.688	11/16	9.91			
.075		1.08	.719	23/32	10.35			
.080		1.15	**.750**	¾	10.80			
.085		1.22	.812	13/16	11.69			
.090		1.30	.875	⅞	12.60			
.095		1.37	.938	15/16	13.51			
.100		1.44	**1.000**	1	14.40			
.106		1.53	1.125	1 ⅛	16.20			
.112		1.61	1.250	1 ¼	18.00			
.118		1.70	1.375	1 ⅜	19.80			
.125	⅛	1.80	1.500	1 ½	21.60			

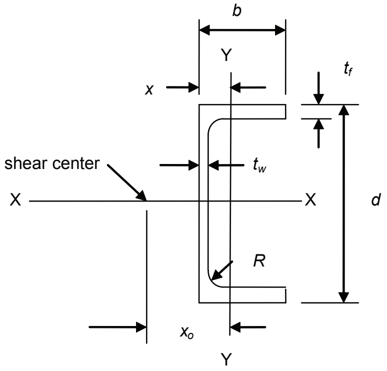


Table 4
ALUMINUM ASSOCIATION STANDARD CHANNELS

Designation	Depth d in.	Width b in.	Flange Thickness t_f in.	Web Thickness t_w in.	Fillet Radius R in.	Area A in²	Axis x-x I_x in⁴	Axis x-x S_x in³	Axis x-x r_x in.	Axis y-y I_y in⁴	Axis y-y S_y in³	Axis y-y r_y in.	Axis y-y x in.	x_o in.	C_w in⁶	J in⁴	r_0 in.
CS 2 × 0.577	2.000	1.000	0.130	0.130	0.100	0.490	0.288	0.288	0.766	0.0450	0.0639	0.303	0.296	0.626	0.0324	0.00274	1.03
CS 2 × 1.07	2.000	1.250	0.260	0.170	0.150	0.911	0.546	0.546	0.774	0.139	0.178	0.390	0.471	0.904	0.0894	0.0171	1.25
CS 3 × 1.14	3.000	1.500	0.200	0.130	0.250	0.965	1.41	0.940	1.21	0.217	0.215	0.474	0.494	1.02	0.332	0.00990	1.65
CS 3 × 1.60	3.000	1.750	0.260	0.170	0.250	1.36	1.97	1.31	1.20	0.417	0.368	0.554	0.617	1.25	0.626	0.0246	1.82
CS 4 × 1.74	4.000	2.000	0.230	0.150	0.250	1.48	3.91	1.95	1.63	0.601	0.446	0.638	0.653	1.38	1.65	0.0202	2.22
CS 4 × 2.33	4.000	2.250	0.290	0.190	0.250	1.98	5.21	2.60	1.62	1.02	0.692	0.717	0.775	1.60	2.76	0.0444	2.39
CS 5 × 2.21	5.000	2.250	0.260	0.150	0.300	1.88	7.88	3.15	2.05	0.975	0.642	0.720	0.731	1.54	4.17	0.0314	2.66
CS 5 × 3.09	5.000	2.750	0.320	0.190	0.300	2.63	11.1	4.45	2.06	2.05	1.14	0.884	0.955	1.98	8.70	0.0700	2.99
CS 6 × 2.83	6.000	2.500	0.290	0.170	0.300	2.41	14.4	4.78	2.44	1.53	0.896	0.798	0.788	1.67	9.52	0.0495	3.06
CS 6 × 4.03	6.000	3.250	0.350	0.210	0.300	3.43	21.0	7.01	2.48	3.76	1.76	1.05	1.12	2.34	23.1	0.109	3.57
CS 7 × 3.21	7.000	2.750	0.290	0.170	0.300	2.73	22.1	6.31	2.85	2.10	1.10	0.878	0.842	1.81	17.8	0.0552	3.49
CS 7 × 4.72	7.000	3.500	0.380	0.210	0.300	4.01	33.8	9.65	2.90	5.13	2.23	1.13	1.20	2.52	43.0	0.147	4.01
CS 8 × 4.15	8.000	3.000	0.350	0.190	0.300	3.53	37.4	9.35	3.26	3.25	1.57	0.959	0.934	1.99	36.0	0.102	3.94
CS 8 × 5.79	8.000	3.750	0.410	0.250	0.350	4.92	52.7	13.2	3.27	7.12	2.82	1.20	1.22	2.59	78.5	0.210	4.34
CS 9 × 4.98	9.000	3.250	0.350	0.230	0.350	4.24	54.4	12.1	3.58	4.40	1.89	1.02	0.928	2.02	62.8	0.127	4.24
CS 9 × 6.97	9.000	4.000	0.440	0.290	0.350	5.93	78.3	17.4	3.63	9.60	3.49	1.27	1.25	2.68	135	0.293	4.69
CS 10 × 6.14	10.000	3.500	0.410	0.250	0.350	5.22	83.2	16.6	3.99	6.33	2.55	1.10	1.02	2.20	111	0.209	4.69
CS 10 × 8.36	10.000	4.250	0.500	0.310	0.400	7.11	116	23.2	4.04	13.0	4.46	1.35	1.34	2.84	226	0.444	5.12
CS 12 × 8.27	12.000	4.000	0.470	0.290	0.400	7.04	160	26.6	4.77	11.0	3.85	1.25	1.14	2.47	281	0.367	5.51
CS 12 × 11.8	12.000	5.000	0.620	0.350	0.450	10.1	240	39.9	4.88	25.7	7.59	1.60	1.61	3.40	639	0.948	6.16
CS 14 × 13.9[1]	14.000	6.000	0.640	0.320	0.450	11.8	401	57.3	5.82	44.7	11.2	1.94	2.00	4.25	1510	1.19	7.46

1. New shape; check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

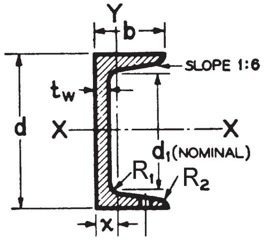


Table 5
AMERICAN STANDARD CHANNELS

Designation	Depth d in.	Width b in.	Flange Tip Thickness t_f in.	Average Flange Thickness t in.	Web Thickness t_w in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	d_1 in.	Area A in^2	Axis x-x			Axis y-y			y-axis Location x in.
										I_x in^4	S_x in^3	r_x in.	I_y in^4	S_y in^3	r_y in.	
C 2 × 1.22	2.000	1.410	0.170	0.273	0.170	0.270	0.100	0.75	1.04	0.622	0.622	0.774	0.172	0.188	0.407	0.49
C 3 × 1.42	3.000	1.410	0.170	0.273	0.170	0.270	0.100	1.75	1.21	1.66	1.10	1.17	0.20	0.20	0.40	0.44
C 3 × 1.73	3.000	1.498	0.170	0.273	0.258	0.270	0.100	1.75	1.47	1.85	1.24	1.12	0.21	0.21	0.41	0.44
C 3 × 2.07	3.000	1.596	0.170	0.273	0.356	0.270	0.100	1.75	1.76	2.07	1.38	1.08	0.31	0.27	0.42	0.46
C 4 × 1.85	4.000	1.580	0.180	0.297	0.180	0.280	0.110	2.75	1.57	3.83	1.92	1.56	0.32	0.28	0.45	0.46
C 4 × 2.16	4.000	1.647	0.180	0.297	0.247	0.280	0.110	2.75	1.84	4.19	2.10	1.51	0.37	0.31	0.45	0.45
C 4 × 2.50	4.000	1.720	0.180	0.297	0.320	0.280	0.110	2.75	2.13	4.58	2.29	1.47	0.43	0.34	0.45	0.46
C 5 × 2.32	5.000	1.750	0.190	0.320	0.190	0.290	0.110	3.75	1.97	7.49	3.00	1.95	0.48	0.38	0.49	0.48
C 5 × 3.11	5.000	1.885	0.190	0.320	0.325	0.290	0.110	3.75	2.64	8.90	3.56	1.83	0.63	0.45	0.49	0.48
C 5 × 3.97	5.000	2.032	0.190	0.320	0.472	0.290	0.110	3.75	3.38	10.4	4.17	1.76	0.81	0.53	0.49	0.51
C 6 × 2.83	6.000	1.920	0.200	0.343	0.200	0.300	0.120	4.50	2.40	13.1	4.37	2.34	0.69	0.49	0.54	0.51
C 6 × 3.00	6.000	1.945	0.200	0.343	0.225	0.300	0.120	4.50	2.55	13.6	4.52	2.31	0.73	0.51	0.54	0.51
C 6 × 3.63	6.000	2.034	0.200	0.343	0.314	0.300	0.120	4.50	3.09	15.2	5.06	2.22	0.87	0.56	0.50	0.50
C 6 × 4.50	6.000	2.157	0.200	0.343	0.438	0.300	0.120	4.50	3.83	17.4	5.80	2.13	1.05	0.64	0.52	0.51
C 7 × 3.54	7.000	2.110	0.210	0.367	0.230	0.310	0.130	5.50	3.01	21.8	6.24	2.69	1.01	0.64	0.58	0.54
C 7 × 4.23	7.000	2.194	0.210	0.367	0.314	0.310	0.130	5.50	3.60	24.2	6.93	2.60	1.17	0.70	0.57	0.52
C 7 × 5.10	7.000	2.299	0.210	0.367	0.419	0.310	0.130	5.50	4.33	27.2	7.78	2.51	1.38	0.78	0.56	0.53
C 7 × 5.96	7.000	2.404	0.210	0.367	0.524	0.310	0.130	5.50	5.07	30.3	8.64	2.44	1.59	0.86	0.56	0.55

										Axis x-x			Axis y-y			
Designation	Depth d in.	Width b in.	Flange Tip Thickness t_f in.	Average Flange Thickness t in.	Web Thickness t_w in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	d_1 in.	Area A in^2	I_x in^4	S_x in^3	r_x in.	I_y in^4	S_y in^3	r_y in.	y-axis Location x in.
C 8 × 4.25	8.000	2.290	0.220	0.390	0.250	0.320	0.130	6.25	3.62	33.9	8.46	3.06	1.40	0.81	0.62	0.56
C 8 × 4.75	8.000	2.343	0.220	0.390	0.303	0.320	0.130	6.25	4.04	36.1	9.03	2.99	1.53	0.85	0.61	0.55
C 8 × 5.62	8.000	2.435	0.220	0.390	0.395	0.320	0.130	6.25	4.78	40.0	10.0	2.90	1.75	0.93	0.61	0.55
C 8 × 6.48	8.000	2.527	0.220	0.390	0.487	0.320	0.130	6.25	5.51	44.0	11.0	2.82	1.98	1.01	0.60	0.57
C 9 × 4.60	9.000	2.430	0.230	0.413	0.230	0.330	0.140	7.25	3.91	47.7	10.6	3.49	1.75	0.96	0.67	0.60
C 9 × 5.19	9.000	2.485	0.230	0.413	0.285	0.330	0.140	7.25	4.41	51.0	11.3	3.40	1.93	1.01	0.66	0.59
C 9 × 6.91	9.000	2.648	0.230	0.413	0.448	0.330	0.140	7.25	5.88	60.9	13.5	3.22	2.42	1.17	0.64	0.58
C 9 × 8.65	9.000	2.812	0.230	0.413	0.612	0.330	0.140	7.25	7.35	70.9	15.8	3.11	2.94	1.34	0.63	0.61
C 10 × 5.28	10.000	2.600	0.240	0.437	0.240	0.340	0.140	8.25	4.49	67.4	13.5	3.87	2.28	1.16	0.71	0.63
C 10 × 6.91	10.000	2.739	0.240	0.437	0.379	0.340	0.140	8.25	5.88	79.0	15.8	3.66	2.81	1.32	0.69	0.61
C 10 × 8.64	10.000	2.886	0.240	0.437	0.526	0.340	0.140	8.25	7.35	91.2	18.2	3.52	3.36	1.48	0.68	0.62
C 10 × 10.4	10.000	3.033	0.240	0.437	0.673	0.340	0.140	8.25	8.82	104	20.7	3.43	3.95	1.66	0.67	0.65
C 12 × 7.41	12.000	2.960	0.280	0.502	0.300	0.380	0.170	10.0	6.30	132	22.0	4.57	3.99	1.76	0.80	0.69
C 12 × 8.64	12.000	3.047	0.280	0.502	0.387	0.380	0.170	10.0	7.35	144	24.1	4.43	4.47	1.89	0.78	0.67
C 12 × 10.4	12.000	3.170	0.280	0.502	0.510	0.380	0.170	10.0	8.82	162	27.0	4.29	5.14	2.06	0.76	0.67
C 12 × 12.1	12.000	3.292	0.280	0.502	0.632	0.380	0.170	10.0	10.3	180	29.9	4.18	5.82	2.24	0.75	0.69
C 15 × 11.7	15.000	3.400	0.400	0.650	0.400	0.500	0.240	12.4	9.96	315	42.0	5.62	8.13	3.11	0.90	0.79
C 15 × 17.3	15.000	3.716	0.400	0.650	0.716	0.500	0.240	12.4	14.7	404	53.8	5.24	11.0	3.78	0.87	0.80

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

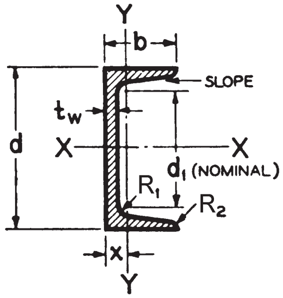


Table 6
CAR AND SHIPBUILDING CHANNELS

Designation	Depth d in.	Width b in.	Avg Flange Thickness t_f in.	Web Thickness t_w in.	Flange Slope	Fillet Radius R_1 in.	Tip Radius R_2 in.	d_1 in.	Area A in²	Axis x-x I_x in.⁴	Axis x-x S_x in.³	Axis x-x r_x in.	Axis y-y I_y in.⁴	Axis y-y S_y in.³	Axis y-y r_y in.	Axis y-y x in.
CS 3 × 2.23	3.000	2.000	0.320	0.250	1:12.1	0.250	0	1.75	1.90	2.61	1.74	1.17	0.68	0.52	0.60	0.68
CS 3 × 2.70	3.000	2.000	0.375	0.375	0	0.188	0.375	0.875	2.30	2.89	1.92	1.12	0.78	0.59	0.58	0.67
CS 4 × 3.32	4.000	2.500	0.344	0.318	1:34.9	0.375	0.125	2.38	2.82	6.84	3.42	1.56	1.62	0.95	0.76	0.81
CS 5 × 5.82	5.000	2.875	0.562	0.438	1:9.8	0.250	0.094	3.00	4.95	18.1	7.25	1.91	3.57	1.87	0.85	0.96
CS 6 × 5.77	6.000	3.000	0.375	0.500	0	0.375	0.250	4.50	4.91	24.1	8.02	2.21	3.52	1.61	0.85	0.81
CS 6 × 5.93	6.000	3.500	0.442	0.375	1:49.6	0.480	0.420	4.00	5.04	28.2	9.41	2.37	5.58	2.31	1.05	1.09
CS 8 × 6.59	8.000	3.000	0.468	0.380	1:14.43	0.550	0.220	5.75	5.60	54.2	13.5	3.11	4.10	1.88	0.86	0.81
CS 8 × 7.86	8.000	3.500	0.524	0.425	1:28.5	0.525	0.375	5.75	6.68	63.8	15.9	3.09	7.06	2.84	1.03	1.01
CS 10 × 8.58	10.000	3.500	0.544	0.375	1:9	0.625	0.188	7.50	7.30	110	21.9	3.88	7.19	2.80	0.99	0.93
CS 10 × 9.32	10.000	3.563	0.544	0.438	1:9	0.625	0.188	7.50	7.93	115	24.0	3.81	7.73	2.93	0.99	0.92
CS 10 × 10.1	10.000	3.625	0.544	0.500	1:9	0.625	0.188	7.50	8.55	120	24.0	3.75	8.25	3.04	0.98	0.91

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data.*

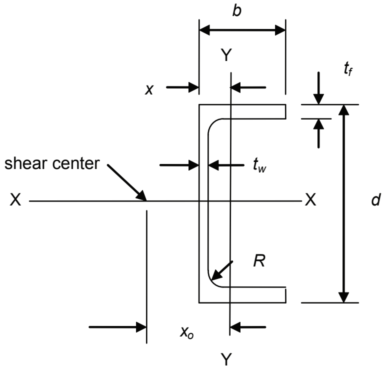


Table 7
CANADIAN CHANNELS

							Axis x-x			Axis y-y							
Designation	Depth d in.	Width b in.	Flange Thickness t_f in.	Web Thickness t_w in.	Fillet Radius R in.	Area A in^2	I_x in^4	S_x in^3	r_x in.	I_y in^4	S_y in^3	r_y in.	x in.	x_o in.	C_w in^6	J in^4	r_0 in.
CS 2 × 0.706	2.000	1.500	0.125	0.125	0.125	0.600	0.391	0.391	0.807	0.137	0.136	0.477	0.493	1.06	0.0938	0.0031	1.42
CS 2.25 × 0.86	2.250	1.000	0.188	0.188	0.062	0.730	0.505	0.449	0.832	0.062	0.090	0.292	0.303	0.605	0.0589	0.0086	1.07
CS 3 × 1.48	3.000	1.500	0.250	0.188	0.312	1.26	1.72	1.15	1.17	0.268	0.265	0.461	0.489	0.981	0.415	0.021	1.59
CS 3 × 1.85	3.000	1.500	0.312	0.250	0.312	1.57	2.03	1.35	1.14	0.321	0.322	0.452	0.502	0.971	0.501	0.043	1.56
CS 3 × 2.18	3.000	2.000	0.312	0.250	0.188	1.86	2.56	1.71	1.17	0.730	0.568	0.627	0.714	1.44	1.09	0.053	1.96
CS 4 × 1.90	4.000	1.620	0.281	0.188	0.375	1.62	3.95	1.98	1.56	0.396	0.355	0.495	0.504	1.01	1.11	0.032	1.92
CS 4 × 2.24	4.000	1.750	0.281	0.250	0.375	1.90	4.41	2.21	1.52	0.514	0.417	0.520	0.519	1.05	1.49	0.044	1.92
CS 4 × 2.02	4.000	2.000	0.250	0.188	0.375	1.72	4.36	2.18	1.59	0.667	0.486	0.623	0.627	1.31	1.84	0.029	2.15
CS 4 × 2.53	4.000	2.000	0.312	0.250	0.375	2.15	5.21	2.60	1.56	0.810	0.595	0.613	0.638	1.30	2.25	0.058	2.12
CS 4 × 2.90	4.000	2.500	0.312	0.250	0.375	2.46	6.27	3.14	1.60	1.52	0.919	0.786	0.842	1.74	4.13	0.068	2.49
CS 5 × 2.51	5.000	2.000	0.312	0.188	0.375	2.13	8.45	3.38	1.99	0.832	0.607	0.625	0.630	1.29	3.59	0.050	2.45
CS 5 × 3.11	5.000	2.000	0.343	0.281	0.375	2.64	9.59	3.84	1.90	0.942	0.669	0.597	0.592	1.20	4.27	0.086	2.33
CS 5 × 3.05	5.000	2.500	0.312	0.218	0.437	2.60	10.5	4.18	2.01	1.60	0.944	0.786	0.801	1.67	6.86	0.066	2.73
CS 5 × 3.55	5.000	2.500	0.375	0.250	0.437	3.02	12.0	4.79	1.99	1.86	1.11	0.784	0.830	1.69	7.89	0.110	2.73
CS 6 × 3.60	6.000	2.000	0.375	0.281	0.437	3.06	15.8	5.26	2.27	1.06	0.740	0.588	0.569	1.13	7.04	0.109	2.61
CS 6 × 3.51	6.000	2.500	0.312	0.250	0.437	2.99	16.4	5.47	2.34	1.74	0.978	0.764	0.719	1.52	11.2	0.079	2.90
CS 6 × 6.42	6.000	3.500	0.500	0.375	0.437	5.46	30.9	10.3	2.38	6.62	2.87	1.10	1.19	2.44	40.3	0.380	3.58
CS 7 × 3.90	7.000	2.500	0.375	0.218	0.437	3.32	25.8	7.37	2.79	2.02	1.16	0.781	0.759	1.57	17.3	0.109	3.29
CS 7 × 4.61	7.000	3.000	0.375	0.250	0.500	3.92	30.8	8.79	2.80	3.47	1.67	0.941	0.921	1.94	29.5	0.138	3.53
CS 8 × 4.65	8.000	2.750	0.375	0.250	0.437	3.96	39.0	9.74	3.14	2.83	1.44	0.846	0.781	1.65	32.2	0.134	3.65
CS 8 × 5.56	8.000	3.000	0.437	0.281	0.500	4.73	47.3	11.8	3.16	4.10	1.95	0.931	0.900	1.87	46.1	0.220	3.79
CS 10 × 6.23	10.000	3.000	0.437	0.281	0.500	5.29	79.9	16.0	3.89	4.39	2.01	0.911	0.819	1.73	79.3	0.234	4.35
CS 10 × 7.58	10.000	3.500	0.500	0.312	0.562	6.44	101	20.1	3.95	7.59	3.07	1.09	1.03	2.15	134	0.383	4.63
CS 10 × 19.0	10.000	4.000	1.250	0.812	0.500	16.2	223	44.5	3.71	23.3	8.94	1.20	1.39	2.49	402	6.547	4.62
CS 12 × 10.3	12.000	4.000	0.562	0.375	0.625	8.74	192	32.0	4.69	13.1	4.56	1.22	1.13	2.38	338	0.665	5.40

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

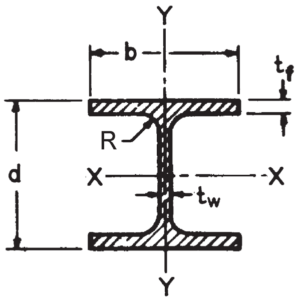


Table 8
ALUMINUM ASSOCIATION STANDARD I-BEAMS

	Depth	Width	Flange Thickness	Web Thickness	Fillet Radius	Area	Axis x-x			Axis y-y					
Designation	d in.	b in.	t_f in.	t_w in.	R in.	A in^2	I_x in^4	S_x in^3	r_x in.	I_y in^4	S_y in^3	r_y in.	C_w in^6	J in^4	r_o in.
I 3 × 1.64	3.000	2.500	0.200	0.130	0.250	1.39	2.24	1.49	1.27	0.522	0.418	0.613	1.02	0.0192	1.41
I 3 × 2.03	3.000	2.500	0.260	0.150	0.250	1.73	2.71	1.81	1.25	0.679	0.543	0.627	1.27	0.0374	1.40
I 4 × 2.31	4.000	3.000	0.230	0.150	0.250	1.96	5.62	2.81	1.69	1.04	0.691	0.727	3.68	0.0333	1.84
I 4 × 2.79	4.000	3.000	0.290	0.170	0.250	2.38	6.71	3.36	1.68	1.31	0.872	0.742	4.50	0.0608	1.84
I 5 × 3.70	5.000	3.500	0.320	0.190	0.300	3.15	13.9	5.58	2.11	2.29	1.31	0.853	12.5	0.0984	2.27
I 6 × 4.03	6.000	4.000	0.290	0.190	0.300	3.43	22.0	7.33	2.53	3.10	1.55	0.951	25.3	0.0888	2.71
I 6 × 4.69	6.000	4.000	0.350	0.210	0.300	3.99	25.5	8.50	2.53	3.74	1.87	0.968	29.8	0.145	2.71
I 7 × 5.80	7.000	4.500	0.380	0.230	0.300	4.93	42.9	12.3	2.95	5.78	2.57	1.08	63.3	0.206	3.14
I 8 × 6.18	8.000	5.000	0.350	0.230	0.300	5.26	59.7	14.9	3.37	7.30	2.92	1.18	107	0.188	3.57
I 8 × 7.02	8.000	5.000	0.410	0.250	0.300	5.97	67.8	16.9	3.37	8.55	3.42	1.20	123	0.286	3.57
I 9 × 8.36	9.000	5.500	0.440	0.270	0.300	7.11	102	22.7	3.79	12.2	4.44	1.31	224	0.386	4.01
I 10 × 8.65	10.000	6.000	0.410	0.250	0.400	7.35	132	26.4	4.24	14.8	4.93	1.42	340	0.360	4.47
I 10 × 10.3	10.000	6.000	0.500	0.290	0.400	8.75	156	31.2	4.22	18.0	6.01	1.44	407	0.620	4.46
I 12 × 11.7	12.000	7.000	0.470	0.290	0.400	9.92	256	42.6	5.07	26.9	7.69	1.65	894	0.621	5.33
I 12 × 14.3	12.000	7.000	0.620	0.310	0.400	12.2	317	52.9	5.11	35.5	10.1	1.71	1149	1.26	5.39
I 14 × 16.0[1]	14.000	8.000	0.600	0.300	0.400	14.2	489	69.9	6.00	51.2	12.8	1.94	2300	1.31	6.31

1. New shape; check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

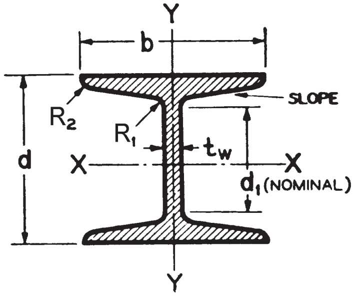


Table 9
WIDE FLANGE BEAMS

Designation	Depth d in.	Width b in.	Avg Flange Thickness t_f in.	Web Thickness t_w in.	Flange Slope	Fillet Radius R_1 in.	Tip Radius R_2 in.	d_1 in.	Area A in²	Axis x-x			Axis y-y		
										I_x in.⁴	S_x in.³	r_x in.	I_y in.⁴	S_y in.³	r_y in.
WF 2 × 1.43	2.000	2.000	0.232	0.188	1:11.4	0.188	0.094	1.13	1.22	0.782	0.782	0.80	0.275	0.275	0.47
WF 4 × 4.76	4.000	4.000	0.370	0.313	1:11.3	0.313	0.145	2.38	4.05	10.8	5.40	1.63	3.52	1.76	0.93
WF 5 × 6.49	5.000	5.000	0.415	0.313	1:13.6	0.313	0.165	3.38	5.52	23.9	9.58	2.08	7.73	3.09	1.18
WF 6 × 4.16	6.000	4.000	0.279	0.230	0	0.250	0	4.88	3.54	21.8	7.25	2.48	2.98	1.49	0.92
WF 6 × 5.40	6.000	6.000	0.269	0.240	0	0.250	0	4.88	4.59	30.2	10.1	2.56	9.69	3.23	1.45
WF 6 × 7.85	6.000	5.930	0.451	0.250	1:15.6	0.313	0.180	4.38	6.68	44.3	14.8	2.57	14.0	4.67	1.45
WF 6 × 8.30	6.000	6.000	0.451	0.313	1:15.6	0.313	0.180	4.38	7.06	45.4	15.1	2.54	14.5	4.83	1.43
WF 6 × 9.18	6.000	6.130	0.451	0.438	1:15.6	0.313	0.180	4.38	7.81	47.6	15.9	2.47	15.5	5.16	1.41
WF 8 × 5.90	8.000	5.250	0.308	0.230	0	0.320	0	6.75	5.02	56.7	14.2	3.36	7.44	2.83	1.22
WF 8 × 8.32	8.000	6.500	0.398	0.245	0	0.400	0	6.38	7.08	84.2	21.0	3.44	18.2	5.61	1.61
WF 8 × 10.7	8.000	8.000	0.433	0.288	0	0.400	0	6.38	9.12	110	27.4	3.47	37.0	9.24	2.01
WF 8 × 11.2	8.000	7.940	0.458	0.313	1:18.9	0.313	0.179	6.25	9.55	113	28.3	3.45	33.9	8.47	1.88
WF 8 × 11.8	8.000	8.000	0.458	0.375	1:18.9	0.313	0.179	6.25	10.1	116	29.0	3.40	34.7	8.68	1.86
WF 8 × 13.0	8.000	8.130	0.458	0.500	1:18.9	0.313	0.179	6.25	11.1	121	30.3	3.31	36.5	9.13	1.82
WF 10 × 11.4	9.750	7.964	0.433	0.292	0	0.500	0	7.88	9.71	171	35.1	4.20	36.5	9.16	1.94
WF 10 × 7.30	9.900	5.750	0.340	0.240	0	0.312	0	8.56	6.21	107	21.6	4.15	10.8	3.75	1.32
WF 12 × 13.8	11.940	8.000	0.516	0.294	0	0.600	0	9.69	11.8	310	51.9	5.13	44.1	11.0	1.94
WF 12 × 18.3	12.060	10.000	0.576	0.345	0	0.600	0	9.69	15.6	426	70.7	5.23	96.1	19.2	2.48

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

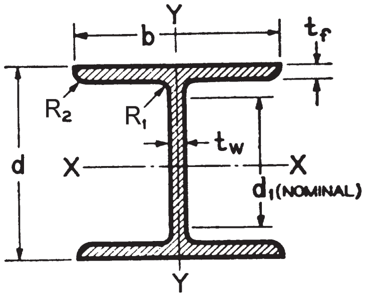


Table 10
WIDE FLANGE BEAMS–ARMY-NAVY SERIES

									Axis x-x			Axis y-y					
Designation	Depth d in.	Width b in.	Flange Thickness t_f in.	Web Thickness t_w in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	d_1 in.	Area A in^2	I_x in^4	S_x in^3	r_x in.	I_y in^4	S_y in^3	r_y in.	C_w in^6	J in^4	r_0 in.
WF(A-N) 2 × 0.928	2.500	2.000	0.125	0.125	0.156	0.125	2.00	0.789	0.831	0.665	1.03	0.155	0.155	0.443	0.235	0.00407	1.12
WF(A-N) 3 × 0.769	3.000	2.000	0.094	0.094	0.156	0.094	2.50	0.654	0.992	0.661	1.23	0.118	0.118	0.426	0.265	0.00189	1.30
WF(A-N) 3 × 1.00	3.000	2.000	0.125	0.125	0.156	0.125	2.50	0.851	1.26	0.841	1.22	0.155	0.155	0.426	0.344	0.00439	1.29
WF(A-N) 4 × 1.14	4.000	2.000	0.125	0.125	0.125	0.125	3.50	0.969	2.42	1.21	1.58	0.155	0.155	0.400	0.626	0.00505	1.63
WF(A-N) 4 × 1.79	4.000	3.000	0.156	0.156	0.188	0.156	3.25	1.52	4.14	2.07	1.65	0.659	0.439	0.658	2.59	0.0123	1.78
WF(A-N) 4 × 2.35	4.000	3.500	0.188	0.188	0.188	0.188	3.25	2.00	5.52	2.76	1.66	1.26	0.719	0.793	4.88	0.0235	1.84
WF(A-N) 4 × 3.06	4.000	3.500	0.250	0.250	0.188	0.250	3.00	2.60	6.97	3.48	1.64	1.64	0.936	0.793	6.28	0.0547	1.82
WF(A-N) 4 × 4.14	4.000	4.000	0.312	0.312	0.250	0.312	2.75	3.52	9.39	4.70	1.63	3.03	1.51	0.927	11.3	0.115	1.88
WF(A-N) 5 × 5.36	5.000	5.000	0.312	0.312	0.312	0.125	3.75	4.56	19.7	7.86	2.08	6.43	2.57	1.19	35.7	0.146	2.39

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

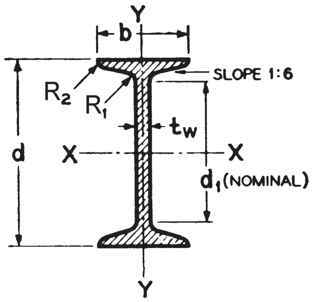


Table 11
AMERICAN STANDARD I-BEAMS

Designation	Depth d in.	Width b in.	Flange Tip Thickness t_f in.	Avg Flange Thickness t in.	Web Thickness t_w in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	d_1 in.	Area A in^2	Axis x-x			Axis y-y		
										I_x in^4	S_x in^3	r_x in.	I_y in^4	S_y in^3	r_y in.
S 3 × 1.96	3.000	2.330	0.170	0.260	0.170	0.270	0.100	1.75	1.67	2.52	1.68	1.23	0.46	0.39	0.52
S 3 × 2.59	3.000	2.509	0.170	0.260	0.349	0.270	0.100	1.75	2.21	2.93	1.95	1.15	0.59	0.47	0.52
S 4 × 2.64	4.000	2.660	0.190	0.293	0.190	0.290	0.110	2.75	2.25	6.06	3.03	1.64	0.76	0.57	0.58
S 4 × 3.28	4.000	2.796	0.190	0.293	0.326	0.290	0.110	2.75	2.79	6.79	3.39	1.56	0.90	0.65	0.57
S 5 × 3.43	5.000	3.000	0.210	0.326	0.210	0.310	0.130	3.50	2.92	12.3	4.90	2.05	1.21	0.81	0.64
S 5 × 4.23	5.000	3.137	0.210	0.326	0.347	0.310	0.130	3.50	3.60	13.7	5.48	1.95	1.41	0.90	0.63
S 5 × 5.10	5.000	3.284	0.210	0.326	0.494	0.310	0.130	3.50	4.34	15.2	6.09	1.87	1.66	1.01	0.62
S 6 × 4.30	6.000	3.330	0.230	0.359	0.230	0.330	0.140	4.50	3.66	22.1	7.36	2.46	1.82	1.09	0.71
S 6 × 5.10	6.000	3.443	0.230	0.359	0.343	0.330	0.140	4.50	4.34	24.1	8.04	2.36	2.04	1.19	0.69
S 6 × 5.96	6.000	3.565	0.230	0.359	0.465	0.330	0.140	4.50	5.07	26.3	8.77	2.28	2.31	1.30	0.68
S 7 × 6.05	7.000	3.755	0.250	0.392	0.345	0.350	0.150	5.25	5.15	39.4	11.3	2.77	2.88	1.53	0.75
S 8 × 6.35	8.000	4.000	0.270	0.425	0.270	0.370	0.160	6.25	5.40	57.6	14.4	3.27	3.73	1.86	0.83
S 8 × 7.96	8.000	4.171	0.270	0.425	0.441	0.370	0.160	6.25	6.77	64.9	16.2	3.10	4.31	2.07	0.80
S 8 × 8.81	8.000	4.262	0.270	0.425	0.532	0.370	0.160	6.25	7.49	68.7	17.2	3.03	4.66	2.19	0.79
S 9 × 7.51	9.000	4.330	0.290	0.458	0.290	0.390	0.170	7.00	6.38	85.9	19.1	3.67	5.09	2.35	0.89
S 10 × 8.76	10.000	4.660	0.310	0.491	0.310	0.410	0.190	8.00	7.45	123	24.5	4.07	6.78	2.91	0.95
S 10 × 10.4	10.000	4.797	0.310	0.491	0.447	0.410	0.190	8.00	8.82	135	27.0	3.91	7.50	3.13	0.92
S 10 × 12.1	10.000	4.944	0.310	0.491	0.594	0.410	0.190	8.00	10.3	147	29.4	3.78	8.36	3.38	0.90
S 12 × 11.0	12.000	5.000	0.350	0.544	0.350	0.450	0.210	9.75	9.35	218	36.4	4.83	9.35	3.74	1.00
S 12 × 12.1	12.000	5.078	0.350	0.544	0.428	0.450	0.210	9.75	10.3	229	38.2	4.72	9.87	3.89	0.98
S 12 × 14.1	12.000	5.250	0.460	0.660	0.460	0.560	0.280	9.25	12.0	272	45.4	4.77	13.5	5.16	1.06
S 12 × 15.6	12.000	5.355	0.460	0.660	0.565	0.560	0.280	9.25	13.2	287	47.9	4.66	14.5	5.42	1.05
S 12 × 17.3	12.000	5.477	0.460	0.660	0.687	0.560	0.280	9.25	14.7	305	50.8	4.56	15.7	5.74	1.03

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

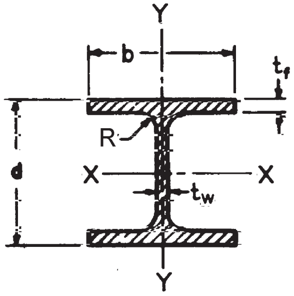


Table 12
CANADIAN I-BEAMS

Designation	Depth d in.	Width b in.	Flange Thickness t_f in.	Web Thickness t_w in.	Fillet Radius R in.	Area A in²	Axis x-x			Axis y-y					
							I_x in⁴	S_x in³	r_x in.	I_y in⁴	S_y in³	r_y in.	C_w in⁶	J in⁴	r_0 in.
I 3 × 2.16	3.000	2.500	0.250	0.188	0.375	1.84	2.78	1.85	1.23	0.657	0.525	0.597	1.24	0.017	1.37
I 4 × 2.68	4.000	3.000	0.250	0.188	0.375	2.28	6.28	3.14	1.66	1.13	0.754	0.705	3.98	0.017	1.80
I 5 × 4.05	5.000	3.500	0.312	0.250	0.437	3.44	14.5	5.79	2.05	2.24	1.28	0.808	12.3	0.036	2.20
I 6 × 3.92	6.000	3.000	0.312	0.250	0.375	3.34	19.2	6.40	2.40	1.42	0.945	0.652	11.5	0.026	2.49
I 6 × 4.82	6.000	3.500	0.375	0.250	0.438	4.10	24.9	8.28	2.46	2.70	1.54	0.811	21.3	0.043	2.59
I 6 × 5.46	6.000	4.000	0.375	0.281	0.437	4.64	28.2	9.40	2.47	4.02	2.01	0.931	31.8	0.048	2.64
I 7 × 5.79	7.000	4.000	0.375	0.281	0.438	4.92	40.2	11.5	2.86	4.02	2.01	0.904	44.1	0.048	3.00
I 8 × 6.12	8.000	4.000	0.375	0.281	0.437	5.20	54.6	13.6	3.24	4.02	2.01	0.880	58.5	0.048	3.36
I 8 × 8.77	8.000	5.000	0.500	0.312	0.562	7.46	82.4	20.6	3.32	10.5	4.18	1.18	147	0.116	3.53
I 10 × 9.83	10.000	5.000	0.500	0.343	0.562	8.36	139	27.8	4.08	10.5	4.19	1.12	236	0.127	4.23
I 10 × 11.3	10.000	6.000	0.500	0.375	0.562	9.65	163	32.7	4.12	18.1	6.02	1.37	408	0.140	4.34
I 12 × 12.5	12.000	5.500	0.625	0.375	0.625	10.6	252	42.0	4.88	15.7	5.70	1.22	513	0.193	5.03
I 12 × 15.5	12.000	6.500	0.625	0.437	0.625	13.2	317	52.9	4.91	28.7	8.84	1.48	929	0.245	5.13

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

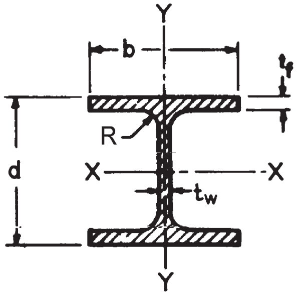


Table 13
CANADIAN WIDE FLANGE BEAMS

Designation	Depth d in.	Width b in.	Flange Thickness t_f in.	Web Thickness t_w in.	Fillet Radius R in.	Area A in^2	Axis x-x I_x in^4	Axis x-x S_x in^3	Axis x-x r_x in.	Axis y-y I_y in^4	Axis y-y S_y in^3	Axis y-y r_y in.	C_w in^6	J in^4	r_0 in.
WF 4 × 4.12	4.000	4.000	0.312	0.250	0.437	3.50	9.72	4.86	1.67	3.34	1.67	0.977	11.4	0.036	1.93
WF 6 × 7.61	6.000	6.000	0.375	0.312	0.625	6.47	41.5	13.8	2.53	13.5	4.52	1.45	107	0.117	2.91
WF 6 × 9.66	6.000	6.000	0.500	0.375	0.625	8.21	51.2	17.1	2.50	18.1	6.02	1.48	137	0.176	2.91
WF 8 × 13.1	8.000	8.000	0.500	0.375	0.750	11.1	129	32.2	3.40	42.8	10.7	1.96	601	0.267	3.93

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data.*

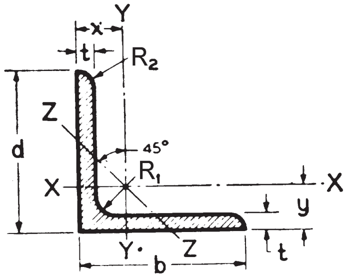


Table 14
ANGLES – EQUAL LEGS

Designation	Depth d in.	Width b in.	Thickness t in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	Weight lb/ft	Area A in^2	Axis x-x, y-y I_x, I_y in^4	 S_x, S_y in^3	 r_x, r_y in.	 x, y in.	Axis z-z I_z in^4	 r_z in.
L 1 1/2 × 1 1/2 × 1/8	1.500	1.500	0.125	0.188	0.125	0.42	0.360	0.0745	0.0684	0.455	0.411	0.0282	0.280
L 1 1/2 × 1 1/2 × 1/4	1.500	1.500	0.250	0.188	0.125	0.81	0.688	0.135	0.130	0.444	0.461	0.0556	0.284
L 1 3/4 × 1 3/4 × 1/8	1.750	1.750	0.125	0.188	0.125	0.50	0.423	0.121	0.0948	0.535	0.473	0.0462	0.330
L 1 3/4 × 1 3/4 × 1/4	1.750	1.750	0.250	0.188	0.125	0.96	0.813	0.223	0.182	0.523	0.524	0.0904	0.333
L 1 3/4 × 1 3/4 × 3/8	1.750	1.750	0.375	0.188	0.125	1.38	1.17	0.306	0.259	0.511	0.570	0.132	0.336
L 2 × 2 × 1/8	2.000	2.000	0.125	0.250	0.125	0.58	0.491	0.185	0.126	0.613	0.531	0.071	0.381
L 2 × 2 × 3/16	2.000	2.000	0.188	0.250	0.125	0.85	0.723	0.268	0.186	0.608	0.560	0.106	0.382
L 2 × 2 × 1/4	2.000	2.000	0.250	0.250	0.125	1.11	0.944	0.342	0.242	0.602	0.585	0.138	0.382
L 2 × 2 × 5/16	2.000	2.000	0.312	0.250	0.125	1.36	1.16	0.410	0.295	0.595	0.609	0.169	0.383
L 2 × 2 × 3/8	2.000	2.000	0.375	0.250	0.125	1.61	1.37	0.474	0.346	0.589	0.632	0.201	0.383
L 2 1/2 × 2 1/2 × 1/8	2.500	2.500	0.125	0.250	0.125	0.72	0.616	0.369	0.200	0.774	0.655	0.143	0.483
L 2 1/2 × 2 1/2 × 3/16	2.500	2.500	0.188	0.250	0.125	1.07	0.911	0.539	0.297	0.769	0.684	0.213	0.484
L 2 1/2 × 2 1/2 × 1/4	2.500	2.500	0.250	0.250	0.125	1.40	1.19	0.695	0.388	0.763	0.710	0.278	0.483
L 2 1/2 × 2 1/2 × 5/16	2.500	2.500	0.312	0.250	0.125	1.73	1.47	0.839	0.475	0.756	0.734	0.341	0.482
L 2 1/2 × 2 1/2 × 3/8	2.500	2.500	0.375	0.250	0.125	2.05	1.74	0.976	0.560	0.749	0.757	0.403	0.481
L 2 1/2 × 2 1/2 × 1/2	2.500	2.500	0.500	0.250	0.125	2.65	2.26	1.22	0.718	0.735	0.802	0.525	0.482
L 3 × 3 × 3/16	3.000	3.000	0.188	0.312	0.250	1.28	1.09	0.908	0.412	0.914	0.797	0.332	0.553
L 3 × 3 × 1/4	3.000	3.000	0.250	0.312	0.250	1.68	1.43	1.19	0.547	0.912	0.826	0.450	0.560
L 3 × 3 × 5/16	3.000	3.000	0.312	0.312	0.250	2.08	1.77	1.45	0.677	0.907	0.852	0.563	0.564
L 3 × 3 × 3/8	3.000	3.000	0.375	0.312	0.250	2.47	2.10	1.71	0.804	0.901	0.877	0.674	0.566
L 3 × 3 × 1/2	3.000	3.000	0.500	0.312	0.250	3.23	2.74	2.17	1.04	0.889	0.924	0.888	0.569
L 3 1/2 × 3 1/2 × 1/4	3.500	3.500	0.250	0.375	0.250	1.99	1.69	1.94	0.758	1.07	0.947	0.739	0.661
L 3 1/2 × 3 1/2 × 5/16	3.500	3.500	0.313	0.375	0.250	2.47	2.10	2.38	0.942	1.07	0.974	0.924	0.664
L 3 1/2 × 3 1/2 × 3/8	3.500	3.500	0.375	0.375	0.250	2.93	2.49	2.79	1.12	1.06	1.00	1.10	0.665
L 3 1/2 × 3 1/2 × 1/2	3.500	3.500	0.500	0.375	0.250	3.83	3.25	3.57	1.45	1.05	1.05	1.45	0.667

				Fillet				Axis x-x, y-y				Axis z-z	
Designation	Depth d in.	Width b in.	Thickness t in.	Radius R_1 in.	Tip Radius R_2 in.	Weight lb/ft	Area A in^2	I_x, I_y in^4	S_x, S_y in^3	r_x, r_y in.	x, y in.	I_z in^4	r_z in.
L 4 × 4 × 1/4	4.000	4.000	0.250	0.375	0.250	2.28	1.94	2.94	1.00	1.23	1.07	1.13	0.762
L 4 × 4 × 5/16	4.000	4.000	0.313	0.375	0.250	2.83	2.41	3.62	1.25	1.23	1.10	1.41	0.765
L 4 × 4 × 3/8	4.000	4.000	0.375	0.375	0.250	3.37	2.86	4.26	1.48	1.22	1.12	1.68	0.766
L 4 × 4 × 7/16	4.000	4.000	0.438	0.375	0.250	3.90	3.32	4.89	1.71	1.21	1.15	1.95	0.766
L 4 × 4 × 1/2	4.000	4.000	0.500	0.375	0.250	4.41	3.75	5.47	1.93	1.21	1.17	2.20	0.766
L 4 × 4 × 9/16	4.000	4.000	0.563	0.375	0.250	4.93	4.19	6.04	2.15	1.20	1.20	2.46	0.766
L 4 × 4 × 5/8	4.000	4.000	0.625	0.375	0.250	5.42	4.61	6.57	2.36	1.19	1.22	2.71	0.766
L 4 × 4 × 11/16	4.000	4.000	0.688	0.375	0.250	5.92	5.03	7.09	2.57	1.19	1.24	2.96	0.767
L 4 × 4 × 3/4	4.000	4.000	0.750	0.375	0.250	6.40	5.44	7.58	2.77	1.18	1.27	3.21	0.768
L 5 × 5 × 3/8	5.000	5.000	0.375	0.500	0.375	4.24	3.60	8.40	2.31	1.53	1.36	3.19	0.941
L 5 × 5 × 7/16	5.000	5.000	0.438	0.500	0.375	4.92	4.18	9.69	2.68	1.52	1.39	3.73	0.945
L 5 × 5 × 1/2	5.000	5.000	0.500	0.500	0.375	5.58	4.74	10.9	3.04	1.52	1.41	4.25	0.947
L 5 × 5 × 9/16	5.000	5.000	0.563	0.500	0.375	6.24	5.31	12.1	3.40	1.51	1.44	4.77	0.948
L 5 × 5 × 5/8	5.000	5.000	0.625	0.500	0.375	6.88	5.85	13.3	3.75	1.50	1.46	5.28	0.949
L 5 × 5 × 3/4	5.000	5.000	0.750	0.500	0.375	8.15	6.93	15.4	4.42	1.49	1.51	6.27	0.951
L 6 × 6 × 3/8	6.000	6.000	0.375	0.500	0.375	5.12	4.35	14.9	3.39	1.85	1.61	5.69	1.14
L 6 × 6 × 7/16	6.000	6.000	0.438	0.500	0.375	5.95	5.06	17.2	3.94	1.84	1.64	6.65	1.15
L 6 × 6 × 1/2	6.000	6.000	0.500	0.500	0.375	6.75	5.74	19.4	4.48	1.84	1.66	7.58	1.15
L 6 × 6 × 5/8	6.000	6.000	0.625	0.500	0.375	8.35	7.10	23.7	5.52	1.83	1.71	9.39	1.15
L 6 × 6 × 3/4	6.000	6.000	0.750	0.500	0.375	9.91	8.43	27.7	6.53	1.81	1.76	11.1	1.15
L 8 × 8 × 1/2	8.000	8.000	0.500	0.625	0.375	9.14	7.77	47.8	8.18	2.48	2.16	18.8	1.55
L 8 × 8 × 5/8	8.000	8.000	0.625	0.625	0.375	11.3	9.63	58.6	10.1	2.47	2.21	23.2	1.55
L 8 × 8 × 3/4	8.000	8.000	0.750	0.625	0.375	13.5	11.5	68.9	12.0	2.45	2.26	27.5	1.55
L 8 × 8 × 1	8.000	8.000	1.000	0.625	0.375	17.7	15.0	88.2	15.6	2.42	2.35	35.9	1.55

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

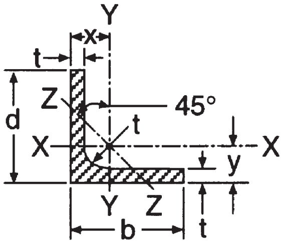


Table 15
SQUARE END ANGLES – EQUAL LEGS

Designation	Depth d in.	Width b in.	Thickness t in.	Weight lb/ft	Area A in^2	Axis x-x, y-y				Axis z-z	
						I_x, I_y in^4	S_x, S_y in^3	r_x, r_y in.	x, y in.	I_z in^4	r_z in.
LS 1 × 1 × 1/8	1.000	1.000	0.125	0.28	0.234	0.0217	0.0309	0.304	0.296	0.00896	0.196
LS 1 × 1 × 3/16	1.000	1.000	0.188	0.40	0.341	0.0300	0.0440	0.297	0.318	0.0129	0.195
LS 1 × 1 × 1/4	1.000	1.000	0.250	0.51	0.438	0.0369	0.0558	0.290	0.339	0.0168	0.196
LS 1 1/4 × 1 1/4 × 1/8	1.250	1.250	0.125	0.35	0.297	0.0439	0.0493	0.385	0.359	0.0179	0.246
LS 1 1/4 × 1 1/4 × 3/16	1.250	1.250	0.188	0.51	0.435	0.0616	0.0709	0.377	0.381	0.0258	0.244
LS 1 1/4 × 1 1/4 × 1/4	1.250	1.250	0.250	0.66	0.563	0.0767	0.0905	0.369	0.403	0.0333	0.243
LS 1 1/2 × 1 1/2 × 1/8	1.500	1.500	0.125	0.42	0.359	0.0778	0.0721	0.465	0.421	0.0315	0.296
LS 1 1/2 × 1 1/2 × 3/16	1.500	1.500	0.188	0.62	0.529	0.110	0.104	0.457	0.444	0.0455	0.293
LS 1 1/2 × 1 1/2 × 1/4	1.500	1.500	0.250	0.81	0.688	0.139	0.134	0.449	0.466	0.0586	0.292
LS 1 3/4 × 1 3/4 × 1/8	1.750	1.750	0.125	0.50	0.422	0.126	0.099	0.546	0.484	0.0507	0.347
LS 1 3/4 × 1 3/4 × 3/16	1.750	1.750	0.188	0.73	0.623	0.179	0.144	0.537	0.507	0.0734	0.343
LS 1 3/4 × 1 3/4 × 1/4	1.750	1.750	0.250	0.96	0.813	0.227	0.186	0.529	0.529	0.0947	0.341
LS 2 × 2 × 1/8	2.000	2.000	0.125	0.57	0.484	0.190	0.131	0.626	0.546	0.0766	0.398
LS 2 × 2 × 3/16	2.000	2.000	0.188	0.84	0.717	0.273	0.191	0.617	0.569	0.111	0.394
LS 2 × 2 × 1/4	2.000	2.000	0.250	1.10	0.938	0.348	0.247	0.609	0.592	0.143	0.391
LS 2 1/2 × 2 1/2 × 1/8	2.500	2.500	0.125	0.72	0.609	0.378	0.207	0.787	0.671	0.152	0.499
LS 2 1/2 × 2 1/2 × 3/16	2.500	2.500	0.188	1.06	0.905	0.548	0.303	0.778	0.695	0.222	0.495
LS 2 1/2 × 2 1/2 × 1/4	2.500	2.500	0.250	1.40	1.19	0.703	0.394	0.769	0.717	0.287	0.491
LS 2 1/2 × 2 1/2 × 5/16	2.500	2.500	0.312	1.72	1.46	0.847	0.481	0.761	0.739	0.350	0.489
LS 3 × 3 × 1/8	3.000	3.000	0.125	0.86	0.734	0.661	0.300	0.949	0.797	0.265	0.601
LS 3 × 3 × 3/16	3.000	3.000	0.188	1.28	1.09	0.964	0.442	0.939	0.820	0.388	0.596
LS 3 × 3 × 1/4	3.000	3.000	0.250	1.69	1.44	1.24	0.577	0.930	0.842	0.504	0.592
LS 3 × 3 × 5/16	3.000	3.000	0.312	2.09	1.77	1.51	0.706	0.922	0.865	0.616	0.589
LS 3 1/2 × 3 1/2 × 1/8	3.500	3.500	0.125	1.01	0.859	1.06	0.411	1.11	0.922	0.425	0.703
LS 4 × 4 × 1/8	4.000	4.000	0.125	1.16	0.984	1.59	0.539	1.27	1.05	0.638	0.805
LS 4 × 4 × 1/4	4.000	4.000	0.250	2.28	1.94	3.04	1.05	1.25	1.09	1.22	0.795

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

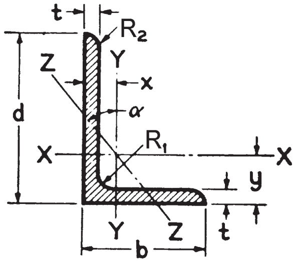


Table 16
ANGLES – UNEQUAL LEGS

								Axis x-x				Axis y-y				Axis z-z		
Designation	Depth d in.	Width b in.	Thick-ness t in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	Weight lb/ft	Area A in²	I_x in⁴	S_x in³	r_x in.	y in.	I_y in⁴	S_y in³	r_y in.	x in.	I_z in⁴	r_z in.	α (deg)
L 1 3/4 × 1 1/4 × 1/8	1.750	1.250	0.125	0.188	0.125	0.42	0.360	0.109	0.0901	0.549	0.544	0.0460	0.0484	0.357	0.300	0.0238	0.257	27.12
L 1 3/4 × 1 1/4 × 3/16	1.750	1.250	0.188	0.188	0.125	0.62	0.530	0.157	0.133	0.544	0.572	0.0659	0.0713	0.353	0.326	0.0355	0.259	26.61
L 1 3/4 × 1 1/4 × 1/4	1.750	1.250	0.250	0.188	0.125	0.81	0.688	0.199	0.172	0.537	0.596	0.0830	0.0921	0.347	0.349	0.0465	0.260	26.09
L 2 × 1 × 3/16	2.000	1.000	0.188	0.188	0.125	0.62	0.530	0.211	0.166	0.631	0.728	0.0351	0.0459	0.257	0.236	0.0223	0.205	14.62
L 2 × 1 1/4 × 1/8	2.000	1.250	0.125	0.188	0.125	0.46	0.392	0.158	0.117	0.635	0.649	0.0477	0.0492	0.349	0.281	0.0265	0.260	21.87
L 2 × 1 1/4 × 1/4	2.000	1.250	0.250	0.188	0.125	0.88	0.751	0.291	0.224	0.623	0.702	0.0862	0.0937	0.339	0.330	0.0515	0.262	20.83
L 2 × 1 1/2 × 1/8	2.000	1.500	0.125	0.188	0.125	0.50	0.423	0.168	0.120	0.630	0.605	0.0810	0.0710	0.438	0.360	0.0407	0.310	29.38
L 2 × 1 1/2 × 3/16	2.000	1.500	0.188	0.188	0.125	0.73	0.624	0.243	0.178	0.625	0.633	0.117	0.105	0.433	0.386	0.0606	0.312	29.00
L 2 × 1 1/2 × 1/4	2.000	1.500	0.250	0.188	0.125	0.96	0.813	0.311	0.231	0.618	0.657	0.148	0.136	0.427	0.410	0.0792	0.312	28.62
L 2 × 1 1/2 × 3/8	2.000	1.500	0.375	0.188	0.125	1.38	1.17	0.428	0.330	0.604	0.704	0.202	0.193	0.415	0.455	0.116	0.314	27.74
L 2 × 1 3/4 × 1/4	2.000	1.750	0.250	0.250	0.125	1.04	0.882	0.328	0.237	0.610	0.617	0.233	0.185	0.514	0.494	0.109	0.352	36.91
L 2 1/4 × 1 1/2 × 1/4	2.250	1.500	0.250	0.250	0.125	1.04	0.882	0.435	0.292	0.702	0.758	0.153	0.138	0.417	0.389	0.0877	0.315	23.46
L 2 1/2 × 1 1/4 × 1/8	2.500	1.250	0.125	0.188	0.094	0.54	0.457	0.298	0.182	0.807	0.867	0.0515	0.0516	0.336	0.252	0.0320	0.265	15.16
L 2 1/2 × 1 1/2 × 1/8	2.500	1.500	0.125	0.250	0.125	0.58	0.491	0.314	0.186	0.800	0.806	0.0860	0.0728	0.418	0.320	0.0492	0.316	20.43
L 2 1/2 × 1 1/2 × 3/16	2.500	1.500	0.188	0.250	0.125	0.85	0.723	0.457	0.275	0.794	0.838	0.124	0.108	0.414	0.347	0.0727	0.317	20.07
L 2 1/2 × 1 1/2 × 1/4	2.500	1.500	0.250	0.250	0.125	1.11	0.944	0.586	0.358	0.787	0.864	0.158	0.140	0.408	0.372	0.0946	0.316	19.70
L 2 1/2 × 1 1/2 × 5/16	2.500	1.500	0.312	0.250	0.125	1.36	1.16	0.705	0.437	0.780	0.889	0.188	0.170	0.403	0.395	0.116	0.316	19.29
L 2 1/2 × 1 1/2 × 3/8	2.500	1.500	0.375	0.250	0.125	1.61	1.37	0.816	0.514	0.773	0.914	0.216	0.200	0.398	0.419	0.137	0.316	18.84
L 2 1/2 × 2 × 1/8	2.500	2.000	0.125	0.250	0.125	0.65	0.554	0.345	0.194	0.789	0.722	0.197	0.129	0.596	0.478	0.0955	0.415	32.51
L 2 1/2 × 2 × 3/16	2.500	2.000	0.188	0.250	0.125	0.96	0.817	0.503	0.288	0.784	0.752	0.286	0.191	0.592	0.506	0.142	0.416	32.30
L 2 1/2 × 2 × 1/4	2.500	2.000	0.250	0.250	0.125	1.26	1.07	0.646	0.375	0.778	0.778	0.366	0.249	0.585	0.531	0.185	0.416	32.09
L 2 1/2 × 2 × 5/16	2.500	2.000	0.312	0.250	0.125	1.54	1.31	0.780	0.459	0.770	0.802	0.440	0.304	0.579	0.555	0.226	0.415	31.85
L 2 1/2 × 2 × 3/8	2.500	2.000	0.375	0.250	0.125	1.83	1.55	0.905	0.541	0.763	0.826	0.509	0.358	0.572	0.578	0.267	0.415	31.59
L 3 × 1 1/2 × 1/4	3.000	1.500	0.250	0.312	0.125	1.27	1.08	0.980	0.510	0.954	1.08	0.165	0.142	0.391	0.343	0.106	0.313	14.59
L 3 × 2 × 3/16	3.000	2.000	0.188	0.312	0.188	1.07	0.910	0.821	0.400	0.949	0.947	0.292	0.190	0.567	0.459	0.158	0.416	24.25
L 3 × 2 × 1/4	3.000	2.000	0.250	0.312	0.188	1.40	1.19	1.06	0.526	0.944	0.976	0.377	0.249	0.562	0.485	0.209	0.418	23.95
L 3 × 2 × 5/16	3.000	2.000	0.312	0.312	0.188	1.73	1.47	1.29	0.647	0.938	1.00	0.456	0.306	0.557	0.510	0.257	0.419	23.64
L 3 × 2 × 3/8	3.000	2.000	0.375	0.312	0.188	2.05	1.74	1.51	0.765	0.931	1.03	0.529	0.361	0.551	0.534	0.305	0.419	23.32
L 3 × 2 × 1/2	3.000	2.000	0.500	0.312	0.188	2.65	2.26	1.90	0.987	0.918	1.08	0.659	0.464	0.541	0.580	0.399	0.421	22.61

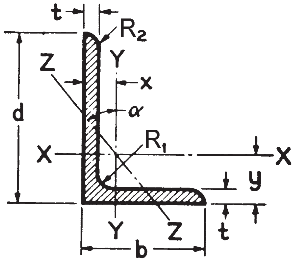


Table 16
ANGLES – UNEQUAL LEGS (Continued)

								Axis x-x				Axis y-y				Axis z-z		
Designation	Depth d in.	Width b in.	Thickness t in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	Weight lb/ft	Area A in^2	I_x in^4	S_x in^3	r_x in.	y in.	I_y in^4	S_y in^3	r_y in.	x in.	I_z in^4	r_z in.	α (deg)
L 3 × 2 1/2 × 1/4	3.000	2.500	0.250	0.312	0.250	1.54	1.31	1.12	0.532	0.927	0.893	0.704	0.380	0.734	0.647	0.323	0.497	34.65
L 3 × 2 1/2 × 5/16	3.000	2.500	0.312	0.312	0.250	1.90	1.61	1.37	0.659	0.922	0.919	0.859	0.470	0.730	0.672	0.404	0.500	34.45
L 3 × 2 1/2 × 3/8	3.000	2.500	0.375	0.312	0.250	2.25	1.92	1.61	0.782	0.916	0.944	1.01	0.557	0.724	0.697	0.484	0.503	34.25
L 3 1/2 × 3 × 1/4	3.500	3.000	0.250	0.375	0.250	1.84	1.57	1.85	0.742	1.09	1.01	1.25	0.559	0.893	0.767	0.562	0.599	36.17
L 3 1/2 × 3 × 5/16	3.500	3.000	0.312	0.375	0.250	2.27	1.93	2.26	0.918	1.08	1.04	1.53	0.692	0.888	0.793	0.701	0.602	36.04
L 3 1/2 × 3 × 3/8	3.500	3.000	0.375	0.375	0.250	2.71	2.30	2.66	1.09	1.08	1.07	1.79	0.822	0.883	0.819	0.838	0.603	35.90
L 3 1/2 × 3 × 1/2	3.500	3.000	0.500	0.375	0.250	3.53	3.00	3.39	1.42	1.06	1.11	2.28	1.07	0.871	0.867	1.10	0.605	35.63
L 4 × 3 × 1/4	4.000	3.000	0.250	0.375	0.250	1.99	1.69	2.69	0.963	1.26	1.21	1.30	0.568	0.875	0.719	0.651	0.620	29.39
L 4 × 3 × 5/16	4.000	3.000	0.312	0.375	0.250	2.46	2.09	3.29	1.19	1.26	1.24	1.59	0.703	0.871	0.746	0.810	0.623	29.19
L 4 × 3 × 3/8	4.000	3.000	0.375	0.375	0.250	2.93	2.49	3.88	1.42	1.25	1.27	1.86	0.836	0.865	0.771	0.967	0.624	29.00
L 4 × 3 × 7/16	4.000	3.000	0.438	0.375	0.250	3.38	2.88	4.44	1.64	1.24	1.29	2.13	0.964	0.859	0.796	1.12	0.624	28.81
L 4 × 3 × 1/2	4.000	3.000	0.500	0.375	0.250	3.83	3.25	4.97	1.85	1.24	1.31	2.37	1.09	0.853	0.819	1.27	0.624	28.62
L 4 × 3 × 5/8	4.000	3.000	0.625	0.375	0.250	4.69	3.99	5.96	2.26	1.22	1.36	2.82	1.32	0.841	0.866	1.56	0.625	28.20
L 4 × 3 1/2 × 5/16	4.000	3.500	0.312	0.375	0.312	2.62	2.23	3.41	1.20	1.24	1.16	2.43	0.938	1.04	0.913	1.06	0.691	37.33
L 4 × 3 1/2 × 3/8	4.000	3.500	0.375	0.375	0.312	3.13	2.66	4.03	1.43	1.23	1.19	2.87	1.12	1.04	0.940	1.28	0.694	37.22
L 4 × 3 1/2 × 1/2	4.000	3.500	0.500	0.375	0.312	4.10	3.49	5.18	1.88	1.22	1.24	3.68	1.46	1.03	0.989	1.70	0.698	37.00
L 5 × 3 × 1/4	5.000	3.000	0.250	0.375	0.312	2.26	1.93	4.90	1.45	1.60	1.62	1.34	0.567	0.834	0.639	0.739	0.620	20.79
L 5 × 3 × 5/16	5.000	3.000	0.312	0.375	0.312	2.81	2.39	6.05	1.81	1.59	1.65	1.65	0.706	0.831	0.666	0.930	0.624	20.54
L 5 × 3 × 3/8	5.000	3.000	0.375	0.375	0.312	3.35	2.85	7.17	2.16	1.59	1.68	1.95	0.843	0.827	0.692	1.12	0.626	20.31
L 5 × 3 × 1/2	5.000	3.000	0.500	0.375	0.312	4.40	3.74	9.26	2.83	1.57	1.73	2.49	1.10	0.816	0.742	1.47	0.628	19.86

								Axis x-x				Axis y-y				Axis z-z		
Designation	Depth d in.	Width b in.	Thick-ness t in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	Weight lb/ft	Area A in^2	I_x in^4	S_x in^3	r_x in.	y in.	I_y in^4	S_y in^3	r_y in.	x in.	I_z in^4	r_z in.	α (deg)
L 5 × 3 1/2 × 5/16	5.000	3.500	0.312	0.438	0.312	3.00	2.55	6.39	1.86	1.58	1.56	2.59	0.965	1.01	0.819	1.35	0.728	26.32
L 5 × 3 1/2 × 3/8	5.000	3.500	0.375	0.438	0.312	3.58	3.05	7.58	2.22	1.58	1.59	3.06	1.15	1.00	0.846	1.63	0.731	26.13
L 5 × 3 1/2 × 1/2	5.000	3.500	0.500	0.438	0.312	4.70	4.00	9.79	2.91	1.56	1.64	3.93	1.51	0.991	0.895	2.14	0.732	25.78
L 5 × 3 1/2 × 5/8	5.000	3.500	0.625	0.438	0.312	5.79	4.92	11.8	3.57	1.55	1.69	4.72	1.84	0.979	0.943	2.64	0.733	25.41
L 6 × 3 x 3/8	6.000	3.000	0.375	0.500	0.375	3.80	3.23	11.8	3.03	1.91	2.11	1.99	0.842	0.786	0.630	1.21	0.612	15.24
L 6 × 3 1/2 × 5/16	6.000	3.500	0.312	0.500	0.312	3.39	2.88	10.6	2.64	1.92	1.97	2.71	0.985	0.971	0.746	1.56	0.736	19.61
L 6 × 3 1/2 × 3/8	6.000	3.500	0.375	0.500	0.312	4.04	3.43	12.6	3.16	1.92	2.00	3.21	1.18	0.967	0.773	1.87	0.738	19.43
L 6 × 3 1/2 × 1/2	6.000	3.500	0.500	0.500	0.312	5.31	4.51	16.4	4.15	1.90	2.06	4.12	1.54	0.956	0.823	2.46	0.738	19.10
L 6 × 3 1/2 × 5/8	6.000	3.500	0.625	0.500	0.312	6.54	5.56	19.8	5.10	1.89	2.11	4.96	1.89	0.944	0.872	3.02	0.737	18.75
L 6 × 4 × 3/8	6.000	4.000	0.375	0.500	0.375	4.24	3.60	13.0	3.19	1.90	1.91	4.66	1.51	1.14	0.920	2.50	0.834	24.33
L 6 × 4 × 7/16	6.000	4.000	0.438	0.500	0.375	4.92	4.18	15.1	3.70	1.90	1.93	5.37	1.76	1.13	0.947	2.92	0.836	24.16
L 6 × 4 × 1/2	6.000	4.000	0.500	0.500	0.375	5.58	4.74	17.0	4.20	1.89	1.96	6.03	1.99	1.13	0.972	3.33	0.838	24.00
L 6 × 4 × 5/8	6.000	4.000	0.625	0.500	0.375	6.88	5.85	20.7	5.18	1.88	2.01	7.30	2.45	1.12	1.02	4.12	0.839	23.68
L 6 × 4 × 3/4	6.000	4.000	0.750	0.500	0.375	8.15	6.93	24.1	6.12	1.87	2.06	8.46	2.89	1.10	1.07	4.88	0.839	23.35
L 7 × 4 × 1/2	7.000	4.000	0.500	0.500	0.375	6.17	5.24	26.1	5.66	2.23	2.39	6.28	2.03	1.09	0.903	3.71	0.842	18.70
L 8 × 6 × 5/8	8.000	6.000	0.625	0.500	0.312	9.84	8.37	53.6	9.74	2.53	2.50	26.0	5.78	1.76	1.51	13.6	1.275	29.07
L 8 × 6 × 11/16	8.000	6.000	0.688	0.500	0.375	10.8	9.15	58.1	10.6	2.52	2.52	28.`0	6.27	1.75	1.53	14.7	1.266	29.03
L 8 × 6 × 3/4	8.000	6.000	0.750	0.500	0.375	11.7	9.93	62.6	11.5	2.51	2.55	30.2	6.79	1.74	1.55	15.9	1.265	28.94

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

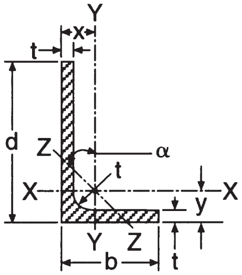


Table 17
SQUARE END ANGLES – UNEQUAL LEGS

						Axis x-x				Axis y-y				Axis z-z		
Designation	Depth d in.	Width b in.	Thick-ness t in.	Weight lb/ft	Area A in^2	I_x in^4	S_x in^3	r_x in.	y in.	I_y in^4	S_y in^3	r_y in.	x in.	I_z in^4	r_z in.	α (deg)
LS 1 × 3/4 × 1/8	1.000	0.750	0.125	0.24	0.203	0.0197	0.0295	0.312	0.332	0.00947	0.0174	0.216	0.207	0.00519	0.160	28.49
LS 1 1/4 × 1 × 1/8	1.250	1.000	0.125	0.31	0.266	0.0408	0.0477	0.392	0.393	0.0233	0.0318	0.296	0.268	0.0119	0.212	32.05
LS 1 1/2 × 3/4 × 1/8	1.500	0.750	0.125	0.31	0.266	0.0613	0.0644	0.480	0.548	0.0105	0.0183	0.199	0.173	0.00683	0.160	14.62
LS 1 1/2 × 1 × 1/8	1.500	1.000	0.125	0.35	0.297	0.0679	0.0677	0.478	0.497	0.0245	0.0325	0.287	0.247	0.0140	0.217	23.77
LS 1 1/2 × 1 × 3/16	1.500	1.000	0.188	0.51	0.435	0.0959	0.0979	0.470	0.520	0.0340	0.0465	0.280	0.270	0.0201	0.215	23.18
LS 1 1/2 × 1 1/4 × 1/8	1.500	1.250	0.125	0.39	0.328	0.0733	0.0702	0.473	0.455	0.0465	0.0505	0.376	0.330	0.0228	0.264	34.37
LS 1 3/4 × 1 × 1/8	1.750	1.000	0.125	0.39	0.328	0.104	0.0909	0.563	0.604	0.0255	0.0331	0.279	0.229	0.0156	0.218	18.50
LS 2 × 1 × 1/8	2.000	1.000	0.125	0.42	0.359	0.150	0.117	0.647	0.715	0.0263	0.0335	0.271	0.215	0.0168	0.216	14.95
LS 2 × 1 × 3/16	2.000	1.000	0.188	0.62	0.529	0.215	0.170	0.638	0.738	0.0366	0.0481	0.263	0.238	0.0240	0.213	14.45
LS 2 × 1 1/2 × 1/8	2.000	1.500	0.125	0.50	0.422	0.173	0.125	0.641	0.618	0.0847	0.0748	0.448	0.368	0.0447	0.326	29.16
LS 2 × 1 1/2 × 3/16	2.000	1.500	0.188	0.73	0.623	0.248	0.183	0.632	0.641	0.120	0.108	0.439	0.391	0.0645	0.322	28.84
LS 2 1/2 × 1 × 1/8	2.500	1.000	0.125	0.50	0.422	0.277	0.178	0.811	0.942	0.0276	0.0342	0.256	0.192	0.0187	0.210	10.54
LS 2 1/2 × 1 1/2 × 1/8	2.500	1.500	0.125	0.57	0.484	0.319	0.191	0.812	0.829	0.0899	0.0767	0.431	0.329	0.0532	0.331	20.36
LS 2 1/2 × 2 × 1/8	2.500	2.000	0.125	0.64	0.547	0.352	0.200	0.802	0.741	0.203	0.135	0.609	0.491	0.102	0.432	32.46
LS 2 1/2 × 2 × 3/16	2.500	2.000	0.188	0.95	0.811	0.510	0.294	0.793	0.764	0.292	0.197	0.600	0.514	0.148	0.427	32.26
LS 3 × 1 × 1/8	3.000	1.000	0.125	0.57	0.484	0.456	0.250	0.971	1.18	0.0286	0.0347	0.243	0.175	0.0201	0.204	7.94
LS 3 × 2 × 1/8	3.000	2.000	0.125	0.72	0.609	0.580	0.282	0.975	0.947	0.213	0.137	0.592	0.447	0.120	0.444	24.28
LS 3 × 2 × 1/4	3.000	2.000	0.250	1.40	1.19	1.09	0.542	0.957	0.993	0.392	0.260	0.574	0.493	0.225	0.435	23.77
LS 3 × 2 × 3/8	3.000	2.000	0.375	2.04	1.73	1.53	0.781	0.940	1.04	0.543	0.371	0.559	0.539	0.320	0.430	23.18
LS 3 × 2 1/2 × 1/4	3.000	2.500	0.250	1.54	1.31	1.17	0.561	0.945	0.911	0.743	0.404	0.753	0.661	0.366	0.528	34.37
LS 3 1/2 × 1 1/4 × 1/8	3.500	1.250	0.125	0.68	0.578	0.750	0.347	1.14	1.34	0.0570	0.0550	0.314	0.215	0.0392	0.261	8.98
LS 4 × 2 × 1/8	4.000	2.000	0.125	0.86	0.734	1.27	0.484	1.31	1.38	0.229	0.141	0.558	0.382	0.144	0.442	15.40
LS 4 × 2 × 1/4	4.000	2.000	0.250	1.69	1.44	2.41	0.936	1.29	1.43	0.421	0.268	0.541	0.429	0.269	0.432	14.95
LS 4 × 3 × 1/8	4.000	3.000	0.125	1.01	0.859	1.45	0.517	1.30	1.19	0.719	0.311	0.914	0.690	0.376	0.661	29.45
LS 5 × 3 × 1/8	5.000	3.000	0.125	1.16	0.984	2.66	0.784	1.64	1.61	0.762	0.319	0.880	0.610	0.447	0.674	20.67
LS 5 × 3 × 1/4	5.000	3.000	0.250	2.28	1.94	5.11	1.53	1.62	1.66	1.44	0.614	0.861	0.657	0.851	0.663	20.36
LS 5 × 4 × 1/8	5.000	4.000	0.125	1.30	1.11	2.92	0.820	1.62	1.44	1.70	0.554	1.24	0.936	0.847	0.874	32.63
LS 5 ¼ × 2 ¼ × 1/8	5.250	2.250	0.125	1.08	0.922	2.75	0.817	1.73	1.89	0.340	0.183	0.607	0.387	0.223	0.491	12.17

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

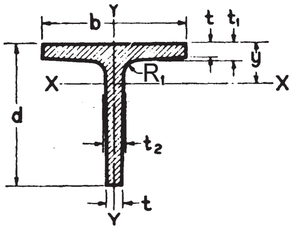


Table 18
TEES

Designation	Thickness				Area	Axis x-x				Axis y-y		
Td × b × Wt	t	t_1	t_2	R_1	A	I_x	S_x	r_x	y	I_y	S_y	r_y
in. in. lb/ft	in.	in.	in.	in.	in^2	in^4	in^3	in.	in.	in^4	in^3	in.
T 1.00 × 1.00 × 0.31	0.125	0.156	0.156	0.125	0.27	0.023	0.032	0.293	0.292	0.011	0.023	0.206
T 1.25 × 1.50 × 0.44	0.125	0.156	0.156	0.125	0.37	0.049	0.053	0.363	0.326	0.038	0.051	0.319
T 1.25 × 1.50 × 0.62	0.188	0.219	0.219	0.125	0.52	0.067	0.075	0.359	0.352	0.056	0.075	0.328
T 1.50 × 1.50 × 0.68	0.188	0.219	0.219	0.188	0.58	0.114	0.108	0.433	0.437	0.056	0.075	0.312
T 1.50 × 1.50 × 0.87	0.25	0.281	0.281	0.188	0.74	0.142	0.137	0.438	0.464	0.075	0.100	0.319
T 2.00 × 1.50 × 0.86	0.188	0.25	0.25	0.188	0.73	0.269	0.195	0.606	0.624	0.060	0.080	0.286
T 2.00 × 2.00 × 1.26	0.25	0.313	0.313	0.25	1.07	0.37	0.26	0.59	0.58	0.18	0.18	0.41
T 2.00 × 2.00 × 1.50	0.313	0.375	0.375	0.25	1.28	0.43	0.31	0.58	0.61	0.23	0.23	0.42
T 2.25 × 2.25 × 1.42	0.25	0.313	0.313	0.25	1.21	0.53	0.33	0.66	0.64	0.26	0.23	0.46
T 1.25 × 2.50 × 1.00	0.188	0.313	0.218	0.188	0.85	0.08	0.09	0.31	0.30	0.285	0.22	0.57
T 2.25 × 2.50 × 1.91	0.313	0.375	0.375	0.25	1.62	0.89	0.50	0.74	0.73	0.44	0.35	0.52
T 3.00 × 2.50 × 2.11	0.313	0.375	0.375	0.25	1.80	1.49	0.72	0.91	0.92	0.44	0.35	0.50
T 2.50 × 3.00 × 2.13	0.313	0.375	0.375	0.313	1.81	0.94	0.51	0.72	0.68	0.75	0.50	0.65
T 3.00 × 3.00 × 2.72	0.375	0.438	0.438	0.313	2.31	1.83	0.86	0.89	0.88	0.90	0.60	0.63
T 2.00 × 4.00 × 2.70	0.375	0.438	0.438	0.25	2.30	0.60	0.40	0.51	0.48	2.10	1.05	0.96
T 3.00 × 4.00 × 2.76	0.313	0.375	0.375	0.375	2.34	1.72	0.77	0.86	0.75	1.77	0.89	0.87
T 4.00 × 4.00 × 3.74	0.375	0.438	0.438	0.5	3.18	4.56	1.58	1.20	1.11	2.12	1.06	0.82
T 5.00 × 4.00 × 4.22	0.375	0.438	0.438	0.5	3.59	8.56	2.43	1.54	1.48	2.13	1.06	0.77
T 5.00 × 4.00 × 5.41	0.5	0.563	0.563	0.5	4.60	10.8	3.14	1.54	1.54	2.83	1.42	0.79
T 3.00 × 4.50 × 2.96	0.313	0.375	0.375	0.375	2.52	1.78	0.78	0.84	0.71	2.52	1.12	1.00
T 3.00 × 5.00 × 4.02	0.375	0.625	0.438	0.375	3.42	2.37	1.06	0.83	0.76	4.13	1.65	1.10
T 1.13 × 1.00 × 0.16	0.063	0.063	0.063	0.094	0.13	0.013	0.017	0.31	0.25	0.007	0.013	0.24
T 1.50 × 1.13 × 0.19	0.062	0.062	0.062	0.062	0.16	0.018	0.021	0.34	0.26	0.017	0.023	0.33
T 1.50 × 1.50 × 0.063	0.187	0.187	0.187	0.187	0.54	0.11	0.10	0.45	0.44	0.054	0.072	0.32
T 1.75 × 1.25 × 0.37	0.109	0.109	0.109	0.062	0.32	0.043	0.045	0.37	0.30	0.049	0.056	0.39
T 2.00 × 3.00 × 0.55	0.094	0.094	0.094	0.157	0.47	0.45	0.22	0.98	0.92	0.063	0.063	0.37
T 2.00 × 1.50 × 0.75	0.187	0.187	0.187	0.187	0.64	0.12	0.11	0.44	0.39	0.13	0.13	0.45
T 2.00 × 2.00 × 1.13	0.250	0.250	0.250	0.250	0.96	0.35	0.25	0.60	0.59	0.17	0.17	0.42
T 2.50 × 2.50 × 1.77	0.312	0.312	0.312	0.312	1.51	0.86	0.49	0.76	0.74	0.42	0.33	0.53
T 3.00 × 3.00 × 2.55	0.375	0.375	0.375	0.375	2.17	1.78	0.84	0.91	0.89	0.86	0.58	0.63
T 4.00 × 2.50 × 2.32	0.312	0.312	0.312	0.312	1.98	0.93	0.49	0.69	0.60	1.68	0.84	0.92
T 4.00 × 4.00 × 3.43	0.375	0.375	0.375	0.375	2.92	4.40	1.54	1.23	1.14	2.03	1.01	0.83
T 5.00 × 3.00 × 3.43	0.375	0.375	0.375	0.375	2.92	2.06	0.90	0.84	0.72	3.93	1.57	1.16
T 6.50 × 10.00 × 10.5(1)	0.500	0.625	0.500	0.625	8.92	89.7	12.7	3.17	2.95	14.4	4.44	1.27

1. $t = 0.625$ for flange and $t = 0.500$ for web
2. Users are encouraged to check availability with suppliers.
3. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

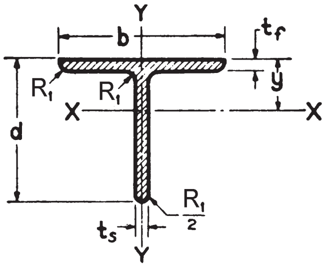


Table 19
ARMY – NAVY AND SPECIAL TEES

					Axis x-x				Axis y-y		
Designation T(A-N) $d \times b \times$ Wt in. in. lb/ft	Stem Thickness t_s in.	Flange Thickness t_f in.	Area A in²	R_1 in.	I_x in⁴	S_x in³	r_x in.	y in.	I_y in⁴	S_y in³	r_y in.
T(A-N) 1.25 × 1.50 × 0.384	0.125	0.125	0.326	0.125	0.045	0.049	0.371	0.327	0.032	0.043	0.314
T(A-N) 1.63 × 1.75 × 0.476	0.125	0.125	0.405	0.125	0.100	0.83	0.496	0.434	0.052	0.059	0.357
T(A-N) 1.00 × 2.00 × 0.421	0.125	0.125	0.358	0.125	0.025	0.032	0.266	0.212	0.078	0.078	0.466
T(A-N) 1.75 × 2.00 × 0.531	0.125	0.125	0.451	0.125	0.128	0.098	0.532	0.451	0.078	0.078	0.415
T(A-N) 1.25 × 2.50 × 0.652	0.156	0.156	0.554	0.125	0.062	0.063	0.333	0.265	0.188	0.151	0.583
T(A-N) 2.00 × 2.50 × 0.789	0.156	0.156	0.671	0.125	0.241	0.161	0.599	0.500	0.189	0.151	0.530
T(A-N) 2.00 × 3.00 × 0.881	0.156	0.156	0.749	0.125	0.254	0.164	0.582	0.456	0.330	0.220	0.663
T(A-N) 2.50 × 3.00 × 1.17	0.188	0.188	0.995	0.188	0.565	0.302	0.753	0.632	0.393	0.262	0.629
T(A-N) 3.00 × 4.00 × 1.50	0.188	0.188	1.28	0.188	1.03	0.448	0.897	0.708	0.947	0.474	0.861
T(A-N) 4.00 × 4.00 × 2.27	0.250	0.250	1.93	0.250	2.98	1.02	1.24	1.08	1.24	0.619	0.801
T(A-N) 5.00 × 4.00 × 2.57	0.250	0.250	2.18	0.250	5.54	1.57	1.59	1.47	1.24	0.620	0.754
T(A-N) 3.00 × 6.00 × 3.24	0.312[1]	0.312	2.75	0.312[1]	1.83	0.77	0.81	0.62	5.63	1.88	1.43
T(A-N) 4.00 × 6.00 × 3.88	0.375[1]	0.313	3.30	0.313[1]	4.78	1.59	1.20	1.00	5.65	1.88	1.31
T(A-N) 4.00 × 6.00 × 4.79	0.375[1]	0.450	4.07	0.312[1]	5.02	1.61	1.11	0.88	8.12	2.71	1.41
T(A-N) 7.50 × 7.50 × 9.46	0. 500[1]	0.750	8.04	0.625[1]	40.3	7.28	2.24	1.96	13.6	4.53	1.30
T(A-N) 7.50 × 7.50 × 14.4	1.13[1]	0.750	12.3	0.625[1]	69.3	14.5	2.38	2.71	14.4	4.80	1.08
T(A-N) 6.00 × 8.00 × 11.2	0.500[1]	0.860	9.56	0.500[1]	22.9	4.82	1.55	1.24	36.8	9.19	1.96

1. Both Flange and stem of these shapes have square ends. Fillet radius R_1 applies only to juncture of stem and flange.
2. Users are encouraged to check availability with suppliers.
3. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

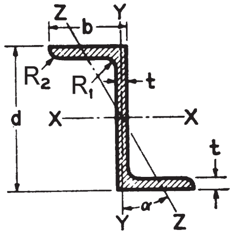


Table 20
ZEES

Designation	Depth d in.	Width b in.	Thickness t in.	Fillet Radius R_1 in.	Tip Radius R_2 in.	Area A in^2	Axis x-x			Axis y-y			Axis z-z		
							I_x in^4	S_x in^3	r_x in.	I_y in^4	S_y in^3	r_y in.	I_z in^4	r_z in.	α deg
Z 1 3/4 × 1 3/4 × 1.09	1.750	1.750	0.188	0.188	0.125	0.925	0.447	0.511	0.695	0.553	0.334	0.773	0.101	0.330	48.82
Z 2 × 1.25 × 0.922	2.000	1.250	0.188	0.188	0.125	0.784	0.459	0.459	0.765	0.186	0.161	0.488	0.0630	0.284	29.20
Z 2 3/8 × 1 1/4 × 1.00	2.375	1.250	0.188	0.188	0.125	0.854	0.695	0.586	0.902	0.187	0.161	0.467	0.0820	0.310	23.20
Z 3 × 2 11/16 × 2.33	3.000	2.688	0.250	0.312	0.250	1.98	2.89	1.92	1.21	2.64	1.03	1.15	0.590	0.545	43.40
Z 3 × 2 11/16 × 3.38	3.000	2.688	0.375	0.312	0.250	2.87	3.86	2.57	1.16	3.76	1.50	1.14	0.820	0.534	44.52
Z 4 × 3 1/16 × 2.85	4.000	3.062	0.250	0.312	0.250	2.42	6.31	3.16	1.61	4.01	1.36	1.29	1.08	0.668	36.78
Z 4 1/16 × 3 1/8 × 3.57	4.062	3.125	0.312	0.312	0.250	3.04	7.96	3.92	1.62	5.23	1.76	1.31	1.39	0.676	37.40
Z 4 1/8 × 3 3/16 × 4.32	4.125	3.188	0.375	0.312	0.250	3.67	9.66	4.69	1.62	6.54	2.18	1.33	1.72	0.684	37.92
Z 4 × 3 1/16 × 4.78	4.000	3.062	0.438	0.312	0.250	4.07	9.69	4.84	1.54	6.53	2.30	1.27	1.74	0.654	37.83
Z 4 1/8 × 3 3/16 × 6.22	4.125	3.188	0.563	0.312	0.250	5.29	12.8	6.19	1.55	9.06	3.12	1.31	2.41	0.675	38.68
Z 5 × 3 1/4 × 4.01	5.000	3.250	0.312	0.312	0.250	3.41	13.4	5.36	1.98	5.93	1.92	1.32	1.89	0.745	30.67
Z 5 1/16 × 3 5/16 × 4.84	5.062	3.312	0.375	0.312	0.250	4.12	16.2	6.41	1.99	7.40	2.37	1.34	2.33	0.752	31.13
Z 5 × 3 1/4 × 6.19	5.000	3.250	0.500	0.312	0.250	5.26	19.2	7.69	1.91	8.82	2.94	1.29	2.82	0.732	31.15

1. Users are encouraged to check availability with suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

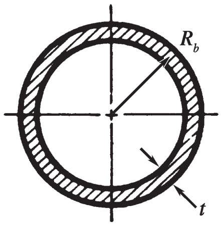


Table 21
ROUND TUBES

Designation	Inside Diameter in.	Weight lb/ft	Area A in^2	I in^4	S in^3	r in.	J in^4	R_b/t
1.500 OD × 0.062 WALL	1.376	0.329	0.280	0.0725	0.097	0.509	0.145	11.6
1.500 OD × 0.094 WALL	1.312	0.488	0.415	0.103	0.137	0.498	0.205	7.5
1.500 OD × 0.125 WALL	1.250	0.635	0.540	0.129	0.172	0.488	0.255	5.5
1.500 OD × 0.156 WALL	1.188	0.775	0.659	0.151	0.201	0.478	0.297	4.3
1.500 OD × 0.188 WALL	1.124	0.911	0.775	0.170	0.227	0.469	0.333	3.5
1.500 OD × 0.250 WALL	1.000	1.15	0.982	0.199	0.266	0.451	0.383	2.5
1.500 OD × 0.375 WALL	0.750	1.56	1.33	0.233	0.311	0.419	0.419	1.5
1.625 OD × 0.125 WALL	1.375	0.693	0.589	0.167	0.205	0.532	0.331	6.0
1.625 OD × 0.188 WALL	1.249	0.998	0.849	0.223	0.274	0.512	0.438	3.8
1.625 OD × 0.250 WALL	1.125	1.27	1.08	0.264	0.324	0.494	0.510	2.8
1.750 OD × 0.125 WALL	1.500	0.750	0.638	0.212	0.242	0.576	0.421	6.5
1.750 OD × 0.188 WALL	1.374	1.08	0.923	0.285	0.326	0.556	0.563	4.2
1.750 OD × 0.250 WALL	1.250	1.39	1.18	0.341	0.389	0.538	0.663	3.0
1.750 OD × 0.375 WALL	1.000	1.90	1.62	0.411	0.470	0.504	0.766	1.8
1.875 OD × 0.125 WALL	1.625	0.808	0.687	0.264	0.282	0.620	0.526	7.0
1.875 OD × 0.188 WALL	1.499	1.17	0.996	0.359	0.383	0.600	0.709	4.5
1.875 OD × 0.250 WALL	1.375	1.50	1.28	0.431	0.460	0.581	0.843	3.3
1.875 OD × 0.375 WALL	1.125	2.08	1.77	0.528	0.563	0.547	0.994	2.0
2.000 OD × 0.125 WALL	1.750	0.866	0.736	0.325	0.325	0.664	0.647	7.5
2.000 OD × 0.188 WALL	1.624	1.26	1.07	0.444	0.444	0.644	0.878	4.8
2.000 OD × 0.250 WALL	1.500	1.62	1.37	0.537	0.537	0.625	1.05	3.5
2.000 OD × 0.312 WALL	1.376	1.95	1.65	0.609	0.609	0.607	1.18	2.7
2.000 OD × 0.375 WALL	1.250	2.25	1.91	0.666	0.666	0.590	1.26	2.2
2.000 OD × 0.500 WALL	1.000	2.77	2.36	0.736	0.736	0.559	1.33	1.5
2.250 OD × 0.125 WALL	2.000	0.981	0.834	0.473	0.420	0.753	0.942	8.5
2.250 OD × 0.188 WALL	1.874	1.43	1.22	0.653	0.580	0.732	1.29	5.5
2.250 OD × 0.250 WALL	1.750	1.85	1.57	0.798	0.709	0.713	1.57	4.0
2.250 OD × 0.312 WALL	1.626	2.23	1.90	0.915	0.813	0.694	1.78	3.1
2.250 OD × 0.375 WALL	1.500	2.60	2.21	1.01	0.897	0.676	1.94	2.5
2.250 OD × 0.500 WALL	1.250	3.23	2.75	1.14	1.01	0.643	2.10	1.8
2.375 OD × 0.188 WALL	1.999	1.52	1.29	0.778	0.655	0.776	1.54	5.8
2.375 OD × 0.250 WALL	1.875	1.96	1.67	0.955	0.804	0.756	1.88	4.3
2.375 OD × 0.375 WALL	1.625	2.77	2.36	1.22	1.03	0.719	2.36	2.7
2.375 OD × 0.500 WALL	1.375	3.46	2.95	1.39	1.17	0.686	2.59	1.9
2.500 OD × 0.125 WALL	2.250	1.10	0.933	0.659	0.528	0.841	1.32	9.5
2.500 OD × 0.188 WALL	2.124	1.61	1.37	0.918	0.735	0.820	1.82	6.1
2.500 OD × 0.250 WALL	2.000	2.08	1.77	1.13	0.906	0.800	2.24	4.5
2.500 OD × 0.312 WALL	1.876	2.52	2.14	1.31	1.05	0.781	2.57	3.5
2.500 OD × 0.375 WALL	1.750	2.94	2.50	1.46	1.17	0.763	2.83	2.8
2.500 OD × 0.500 WALL	1.500	3.69	3.14	1.67	1.34	0.729	3.14	2.0
2.500 OD × 0.625 WALL	1.250	4.33	3.68	1.80	1.44	0.699	3.24	1.5
2.500 OD × 0.750 WALL	1.000	4.85	4.12	1.87	1.49	0.673	3.16	1.2
2.625 OD × 0.250 WALL	2.125	2.19	1.87	1.33	1.01	0.844	2.63	4.8

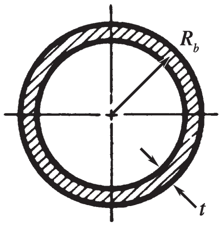


Table 21
ROUND TUBES (Continued)

Designation	Inside Diameter in.	Weight lb/ft	Area A in^2	I in^4	S in^3	r in.	J in^4	R_b/t
2.750 OD × 0.125 WALL	2.500	1.21	1.03	0.890	0.647	0.929	1.78	10.5
2.750 OD × 0.188 WALL	2.374	1.78	1.51	1.25	0.908	0.908	2.48	6.8
2.750 OD × 0.250 WALL	2.250	2.31	1.96	1.55	1.13	0.888	3.07	5.0
2.750 OD × 0.312 WALL	2.126	2.81	2.39	1.80	1.31	0.869	3.55	3.9
2.750 OD × 0.375 WALL	2.000	3.29	2.80	2.02	1.47	0.850	3.95	3.2
2.750 OD × 0.500 WALL	1.750	4.16	3.53	2.35	1.71	0.815	4.47	2.3
2.750 OD × 0.625 WALL	1.500	4.91	4.17	2.56	1.86	0.783	4.71	1.7
2.750 OD × 0.750 WALL	1.250	5.54	4.71	2.69	1.95	0.755	4.71	1.3
2.875 OD × 0.250 WALL	2.375	2.42	2.06	1.79	1.25	0.932	3.55	5.3
2.875 OD × 0.500 WALL	1.875	4.39	3.73	2.75	1.91	0.858	5.26	2.4
3.000 OD × 0.125 WALL	2.750	1.33	1.13	1.17	0.779	1.02	2.33	11.5
3.000 OD × 0.188 WALL	2.624	1.95	1.66	1.65	1.10	0.996	3.28	7.5
3.000 OD × 0.250 WALL	2.500	2.54	2.16	2.06	1.37	0.976	4.08	5.5
3.000 OD × 0.375 WALL	2.250	3.64	3.09	2.72	1.81	0.938	5.33	3.5
3.000 OD × 0.500 WALL	2.000	4.62	3.93	3.19	2.13	0.901	6.14	2.5
3.000 OD × 0.625 WALL	1.750	5.48	4.66	3.52	2.34	0.868	6.58	1.9
3.000 OD × 0.750 WALL	1.500	6.23	5.30	3.73	2.49	0.839	6.71	1.5
3.000 OD × 1.000 WALL	1.000	7.39	6.28	3.93	2.62	0.791	6.28	1.0
3.250 OD × 0.250 WALL	2.750	2.77	2.36	2.67	1.64	1.06	5.30	6.0
3.250 OD × 0.375 WALL	2.500	3.98	3.39	3.56	2.19	1.03	7.00	3.8
3.250 OD × 0.500 WALL	2.250	5.08	4.32	4.22	2.60	0.988	8.17	2.8
3.500 OD × 0.125 WALL	3.250	1.56	1.33	1.89	1.08	1.19	3.77	13.5
3.500 OD × 0.188 WALL	3.124	2.30	1.96	2.69	1.54	1.17	5.36	8.8
3.500 OD × 0.250 WALL	3.000	3.00	2.55	3.39	1.94	1.15	6.74	6.5
3.500 OD × 0.312 WALL	2.876	3.67	3.12	4.01	2.29	1.13	7.94	5.1
3.500 OD × 0.375 WALL	2.750	4.33	3.68	4.56	2.61	1.11	8.99	4.2
3.500 OD × 0.500 WALL	2.500	5.54	4.71	5.45	3.11	1.08	10.6	3.0
3.500 OD × 0.750 WALL	2.000	7.62	6.48	6.58	3.76	1.01	12.3	1.8
3.750 OD × 0.125 WALL	3.500	1.67	1.42	2.34	1.25	1.28	4.68	14.5
3.750 OD × 0.188 WALL	3.374	2.47	2.10	3.35	1.78	1.26	6.67	9.5
3.750 OD × 0.250 WALL	3.250	3.23	2.75	4.23	2.26	1.24	8.42	7.0
3.750 OD × 0.375 WALL	3.000	4.68	3.98	5.73	3.06	1.20	11.3	4.5
3.750 OD × 0.500 WALL	2.750	6.00	5.11	6.90	3.68	1.16	13.5	3.3
4.000 OD × 0.125 WALL	3.750	1.79	1.52	2.86	1.43	1.37	5.71	15.5
4.000 OD × 0.188 WALL	3.624	2.65	2.25	4.10	2.05	1.35	8.18	10.1
4.000 OD × 0.250 WALL	3.500	3.46	2.95	5.20	2.60	1.33	10.4	7.5
4.000 OD × 0.312 WALL	3.376	4.25	3.61	6.19	3.09	1.31	12.3	5.9
4.000 OD × 0.375 WALL	3.250	5.02	4.27	7.09	3.54	1.29	14.0	4.8
4.000 OD × 0.500 WALL	3.000	6.47	5.50	8.59	4.30	1.25	16.8	3.5
4.000 OD × 0.625 WALL	2.750	7.79	6.63	9.76	4.88	1.21	18.9	2.7
4.000 OD × 0.750 WALL	2.500	9.01	7.66	10.6	5.32	1.18	20.2	2.2
4.250 OD × 0.125 WALL	4.000	1.90	1.62	3.45	1.62	1.46	6.89	16.5
4.250 OD × 0.250 WALL	3.750	3.69	3.14	6.31	2.97	1.42	12.6	8.0
4.250 OD × 0.375 WALL	3.500	5.37	4.57	8.65	4.07	1.38	17.1	5.2
4.250 OD × 0.500 WALL	3.250	6.93	5.89	10.5	4.96	1.34	20.7	3.8

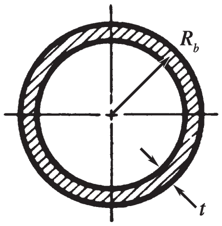


Table 21
ROUND TUBES (Continued)

Designation	Inside Diameter in.	Weight lb/ft	Area A in^2	I in^4	S in^3	r in.	J in^4	R_b/t
4.500 OD × 0.125 WALL	4.250	2.02	1.72	4.11	1.83	1.55	8.22	17.5
4.500 OD × 0.188 WALL	4.124	2.99	2.55	5.93	2.64	1.53	11.8	11.5
4.500 OD × 0.250 WALL	4.000	3.93	3.34	7.56	3.36	1.51	15.1	8.5
4.500 OD × 0.312 WALL	3.876	4.83	4.10	9.05	4.02	1.48	18.0	6.7
4.500 OD × 0.375 WALL	3.750	5.71	4.86	10.4	4.63	1.46	20.7	5.5
4.500 OD × 0.500 WALL	3.500	7.39	6.28	12.8	5.67	1.43	25.1	4.0
4.500 OD × 0.625 WALL	3.250	8.95	7.61	14.7	6.51	1.39	28.6	3.1
4.500 OD × 0.750 WALL	3.000	10.4	8.84	16.2	7.18	1.35	31.1	2.5
4.500 OD × 1.000 WALL	2.500	12.9	11.0	18.2	8.09	1.29	33.7	1.8
4.750 OD × 0.125 WALL	4.500	2.14	1.82	4.86	2.05	1.64	9.71	18.5
4.750 OD × 0.188 WALL	4.374	3.17	2.69	7.02	2.96	1.61	14.0	12.1
4.750 OD × 0.250 WALL	4.250	4.16	3.53	8.97	3.78	1.59	17.9	9.0
4.750 OD × 0.375 WALL	4.000	6.06	5.15	12.4	5.23	1.55	24.7	5.8
4.750 OD × 0.500 WALL	3.750	7.85	6.68	15.3	6.43	1.51	30.1	4.3
5.000 OD × 0.125 WALL	4.750	2.25	1.91	5.69	2.28	1.72	11.4	19.5
5.000 OD × 0.188 WALL	4.624	3.34	2.84	8.24	3.30	1.70	16.5	12.8
5.000 OD × 0.250 WALL	4.500	4.39	3.73	10.6	4.22	1.68	21.0	9.5
5.000 OD × 0.312 WALL	4.376	5.40	4.60	12.7	5.07	1.66	25.2	7.5
5.000 OD × 0.375 WALL	4.250	6.41	5.45	14.7	5.87	1.64	29.1	6.2
5.000 OD × 0.500 WALL	4.000	8.31	7.07	18.1	7.25	1.60	35.8	4.5
5.000 OD × 0.625 WALL	3.750	10.1	8.59	21.0	8.39	1.56	41.1	3.5
5.000 OD × 0.750 WALL	3.500	11.8	10.0	23.3	9.33	1.53	45.2	2.8
5.000 OD × 1.000 WALL	3.000	14.8	12.6	26.7	10.7	1.46	50.3	2.0
5.500 OD × 0.125 WALL	5.250	2.48	2.11	7.63	2.77	1.90	15.2	21.5
5.500 OD × 0.188 WALL	5.124	3.69	3.14	11.1	4.03	1.88	22.1	14.1
5.500 OD × 0.250 WALL	5.000	4.85	4.12	14.2	5.18	1.86	28.4	10.5
5.500 OD × 0.375 WALL	4.750	7.10	6.04	19.9	7.25	1.82	39.6	6.8
5.500 OD × 0.500 WALL	4.500	9.24	7.85	24.8	9.01	1.78	49.1	5.0
5.500 OD × 0.750 WALL	4.000	13.2	11.2	32.4	11.8	1.70	63.1	3.2
5.500 OD × 1.000 WALL	3.500	16.6	14.1	37.6	13.7	1.63	71.6	2.3
6.000 OD × 0.125 WALL	5.750	2.71	2.31	9.96	3.32	2.08	19.9	23.5
6.000 OD × 0.188 WALL	5.624	4.04	3.43	14.5	4.84	2.06	29.0	15.5
6.000 OD × 0.250 WALL	5.500	5.31	4.52	18.7	6.23	2.03	37.3	11.5
6.000 OD × 0.312 WALL	5.376	6.56	5.58	22.6	7.54	2.01	45.1	9.1
6.000 OD × 0.375 WALL	5.250	7.79	6.63	26.3	8.78	1.99	52.4	7.5
6.000 OD × 0.500 WALL	5.000	10.2	8.64	32.9	11.0	1.95	65.3	5.5
6.000 OD × 0.625 WALL	4.750	12.4	10.6	38.6	12.9	1.91	76.2	4.3
6.000 OD × 0.750 WALL	4.500	14.5	12.4	43.5	14.5	1.88	85.2	3.5
6.000 OD × 1.000 WALL	4.000	18.5	15.7	51.1	17.0	1.80	98.2	2.5
6.500 OD × 0.250 WALL	6.000	5.77	4.91	24.0	7.39	2.21	47.9	12.5
6.500 OD × 0.375 WALL	5.750	8.49	7.22	34.0	10.5	2.17	67.7	8.2
6.500 OD × 0.500 WALL	5.500	11.1	9.42	42.7	13.1	2.13	84.8	6.0
6.500 OD × 0.750 WALL	5.000	15.9	13.5	56.9	17.5	2.05	112	3.8
6.750 OD × 0.500 WALL	5.750	11.5	9.82	48.2	14.3	2.22	95.9	6.3
6.750 OD × 0.750 WALL	5.250	16.6	14.1	64.6	19.1	2.14	127	4.0

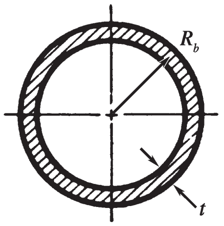


Table 21
ROUND TUBES (Continued)

Designation	Inside Diameter in.	Weight lb/ft	Area A in^2	I in^4	S in^3	r in.	J in^4	R_b/t
7.000 OD × 0.250 WALL	6.500	6.23	5.30	30.2	8.64	2.39	60.4	13.5
7.000 OD × 0.375 WALL	6.250	9.18	7.80	43.0	12.3	2.35	85.6	8.8
7.000 OD × 0.500 WALL	6.000	12.0	10.2	54.2	15.5	2.30	108	6.5
7.000 OD × 0.750 WALL	5.500	17.3	14.7	72.9	20.8	2.23	144	4.2
7.000 OD × 1.000 WALL	5.000	22.2	18.8	87.2	24.9	2.15	170	3.0
7.500 OD × 0.250 WALL	7.000	6.70	5.69	37.5	9.99	2.56	74.8	14.5
7.500 OD × 0.375 WALL	6.750	9.87	8.39	53.4	14.2	2.52	107	9.5
7.500 OD × 0.500 WALL	6.500	12.9	11.0	67.7	18.1	2.48	135	7.0
8.000 OD × 0.125 WALL	7.750	3.64	3.09	24.0	5.99	2.78	47.9	31.5
8.000 OD × 0.250 WALL	7.500	7.16	6.09	45.7	11.4	2.74	91.4	15.5
8.000 OD × 0.375 WALL	7.250	10.6	8.98	65.4	16.4	2.70	131	10.2
8.000 OD × 0.500 WALL	7.000	13.9	11.8	83.2	20.8	2.66	166	7.5
8.000 OD × 0.625 WALL	6.750	17.0	14.5	99.2	24.8	2.62	197	5.9
8.000 OD × 0.750 WALL	6.500	20.1	17.1	113	28.4	2.58	224	4.8
8.000 OD × 1.000 WALL	6.000	25.9	22.0	137	34.4	2.50	269	3.5
8.500 OD × 0.250 WALL	8.000	7.62	6.48	55.2	13.0	2.92	110	16.5
9.000 OD × 0.250 WALL	8.500	8.08	6.87	65.8	14.6	3.09	132	17.5
9.000 OD × 0.375 WALL	8.250	11.9	10.2	94.7	21.0	3.05	189	11.5
9.000 OD × 0.500 WALL	8.000	15.7	13.4	121	26.9	3.01	241	8.5
10.000 OD × 0.250 WALL	9.500	9.01	7.66	91.1	18.2	3.45	182	19.5
10.000 OD × 0.375 WALL	9.250	13.3	11.3	132	26.3	3.41	263	12.8
10.000 OD × 0.500 WALL	9.000	17.5	14.9	169	33.8	3.36	337	9.5
10.000 OD × 0.625 WALL	8.750	21.6	18.4	203	40.6	3.32	404	7.5
10.000 OD × 0.750 WALL	8.500	25.6	21.8	235	46.9	3.28	466	6.2
10.000 OD × 1.000 WALL	8.000	33.3	28.3	290	58.0	3.20	573	4.5
10.500 OD × 0.250 WALL	10.000	9.47	8.05	106	20.1	3.63	211	20.5
10.500 OD × 0.375 WALL	9.750	14.0	11.9	153	29.2	3.58	306	13.5
10.500 OD × 0.500 WALL	9.500	18.5	15.7	197	37.5	3.54	393	10.0
10.500 OD × 0.750 WALL	9.000	27.0	23.0	275	52.3	3.46	546	6.5
11.000 OD × 0.375 WALL	10.250	14.7	12.5	177	32.2	3.76	353	14.2
11.000 OD × 0.500 WALL	10.000	19.4	16.5	228	41.4	3.72	455	10.5
11.000 OD × 0.750 WALL	9.500	28.4	24.2	319	58.0	3.63	634	6.8
11.000 OD × 1.000 WALL	9.000	36.9	31.4	397	72.1	3.55	785	5.0
12.000 OD × 0.250 WALL	11.500	10.9	9.23	159	26.6	4.16	319	23.5
12.000 OD × 0.375 WALL	11.250	16.1	13.7	232	38.6	4.11	463	15.5
12.000 OD × 0.500 WALL	11.000	21.2	18.1	299	49.9	4.07	597	11.5
12.000 OD × 0.750 WALL	10.500	31.2	26.5	421	70.2	3.99	839	7.5
12.000 OD × 1.000 WALL	10.000	40.6	34.6	527	87.8	3.91	1045	5.5

1. Tube can be produced by different methods. Seamless tube is usually required for applications with internal pressure.
2. Users are encouraged to check availability with suppliers. Additional sizes and shapes may be available from suppliers.
3. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

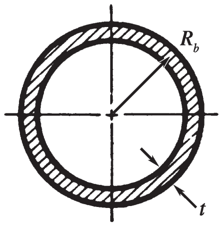


Table 22
PIPES

Nominal Pipe Size	Schedule No.	Outside Diameter OD in.	Inside Diameter ID in.	Wall Thickness t in.	Weight[2] lb/ft	Area A in^2	I in^4	S in^3	r in.	R_b/t
1 1/2	5	1.900	1.770	0.065	0.441	0.375	0.158	0.166	0.649	14.1
	10	1.900	1.682	0.109	0.721	0.613	0.247	0.260	0.634	8.2
	40	1.900	1.610	0.145	0.940	0.799	0.310	0.326	0.623	6.1
	80	1.900	1.500	0.200	1.26	1.07	0.391	0.412	0.605	4.3
	160	1.900	1.338	0.281	1.68	1.43	0.482	0.508	0.581	2.9
2	5	2.375	2.245	0.065	0.555	0.472	0.315	0.265	0.817	17.8
	10	2.375	2.157	0.109	0.913	0.776	0.499	0.420	0.802	10.4
	40	2.375	2.067	0.154	1.26	1.07	0.666	0.561	0.787	7.2
	80	2.375	1.939	0.218	1.74	1.48	0.868	0.731	0.766	4.9
	160	2.375	1.687	0.344	2.58	2.19	1.16	0.980	0.728	3.0
2 1/2	5	2.875	2.709	0.083	0.856	0.728	0.710	0.494	0.988	16.8
	10	2.875	2.635	0.120	1.22	1.04	0.987	0.687	0.975	11.5
	40	2.875	2.469	0.203	2.00	1.70	1.53	1.06	0.947	6.6
	80	2.875	2.323	0.276	2.65	2.25	1.92	1.34	0.924	4.7
	160	2.875	2.125	0.375	3.46	2.95	2.35	1.64	0.894	3.3
3	5	3.500	3.334	0.083	1.05	0.891	1.30	0.744	1.21	20.6
	10	3.500	3.260	0.120	1.50	1.27	1.82	1.04	1.20	14.1
	40	3.500	3.068	0.216	2.62	2.23	3.02	1.72	1.16	7.6
	80	3.500	2.900	0.300	3.55	3.02	3.89	2.23	1.14	5.3
	160	3.500	2.624	0.438	4.95	4.21	5.04	2.88	1.09	3.5
3 1/2	5	4.000	3.834	0.083	1.20	1.02	1.96	0.98	1.39	23.6
	10	4.000	3.760	0.120	1.72	1.46	2.76	1.38	1.37	16.2
	40	4.000	3.548	0.226	3.15	2.68	4.79	2.39	1.34	8.3
	80	4.000	3.364	0.318	4.33	3.68	6.28	3.14	1.31	5.8
4	5	4.500	4.334	0.083	1.35	1.15	2.81	1.25	1.56	26.6
	10	4.500	4.260	0.120	1.94	1.65	3.96	1.76	1.55	18.3
	40	4.500	4.026	0.237	3.73	3.17	7.23	3.21	1.51	9.0
	80	4.500	3.826	0.337	5.18	4.41	9.61	4.27	1.48	6.2
	120	4.500	3.624	0.438	6.57	5.59	11.7	5.18	1.44	4.6
	160	4.500	3.438	0.531	7.79	6.62	13.3	5.90	1.42	3.7
5	5	5.563	5.345	0.109	2.20	1.87	6.95	2.50	1.93	25.0
	10	5.563	5.295	0.134	2.69	2.29	8.43	3.03	1.92	20.3
	40	5.563	5.047	0.258	5.06	4.30	15.2	5.45	1.88	10.3
	80	5.563	4.813	0.375	7.19	6.11	20.7	7.43	1.84	6.9
	120	5.563	4.563	0.500	9.35	7.95	25.7	9.25	1.80	5.1
	160	5.563	4.313	0.625	11.4	9.70	30.0	10.8	1.76	4.0
6	5	6.625	6.407	0.109	2.62	2.23	11.8	3.58	2.30	29.9
	10	6.625	6.357	0.134	3.21	2.73	14.4	4.35	2.30	24.2
	40	6.625	6.065	0.280	6.56	5.58	28.1	8.50	2.25	11.3
	80	6.625	5.761	0.432	9.88	8.40	40.5	12.2	2.19	7.2
	120	6.625	5.501	0.562	12.6	10.7	49.6	15.0	2.15	5.4
	160	6.625	5.187	0.719	15.7	13.3	59.0	17.8	2.10	4.1

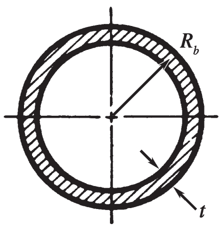


Table 22
PIPES (Continued)

Nominal Pipe Size	Schedule No.	Outside Diameter OD in.	Inside Diameter ID in.	Wall Thickness t in.	Weight[2] lb/ft	Area A in^2	I in^4	S in^3	r in.	R_b/t
8	5	8.625	8.407	0.109	3.43	2.92	26.4	6.13	3.01	39.1
	10	8.625	8.329	0.148	4.64	3.94	35.4	8.21	3.00	28.6
	20	8.625	8.125	0.250	7.74	6.58	57.7	13.4	2.96	16.8
	30	8.625	8.071	0.277	8.54	7.26	63.4	14.7	2.95	15.1
	40	8.625	7.981	0.322	9.88	8.40	72.5	16.8	2.94	12.9
	60	8.625	7.813	0.406	12.3	10.5	88.7	20.6	2.91	10.1
	80	8.625	7.625	0.500	15.0	12.8	106	24.5	2.88	8.1
	100	8.625	7.437	0.594	17.6	15.0	121	28.2	2.85	6.8
	120	8.625	7.187	0.719	21.0	17.9	141	32.6	2.81	5.5
	140	8.625	7.001	0.812	23.4	19.9	154	35.6	2.78	4.8
	160	8.625	6.813	0.906	25.8	22.0	166	38.5	2.75	4.3
10	5	10.750	10.482	0.134	5.26	4.47	63.0	11.7	3.75	39.6
	10	10.750	10.420	0.165	6.45	5.49	76.9	14.3	3.74	32.1
	20	10.750	10.250	0.250	9.70	8.25	114	21.2	3.71	21.0
	30	10.750	10.136	0.307	11.8	10.1	137	25.6	3.69	17.0
	40	10.750	10.020	0.365	14.0	11.9	161	29.9	3.67	14.2
	60	10.750	9.750	0.500	18.9	16.1	212	39.4	3.63	10.3
	80	10.750	9.562	0.594	22.3	19.0	245	45.6	3.60	8.5
	100	10.750	9.312	0.719	26.6	22.7	286	53.3	3.56	7.0
12	5	12.750	12.438	0.156	7.26	6.17	122	19.2	4.45	40.4
	10	12.750	12.390	0.180	8.36	7.11	140	22.0	4.44	34.9
	20	12.750	12.250	0.250	11.5	9.82	192	30.1	4.42	25.0
	30	12.750	12.090	0.330	15.1	12.9	248	39.0	4.39	18.8
	40	12.750	11.938	0.406	18.5	15.7	300	47.1	4.37	15.2
	60	12.750	11.626	0.562	25.3	21.5	400	62.8	4.31	10.8
	80	12.750	11.374	0.688	30.7	26.1	476	74.6	4.27	8.8

1. Sizes are in accordance with ASME Standards B36.10M and B36.19M
2. Weights are for 6061, with a density of 0.098 lb/in^3
3. Check availability of shaded sizes with suppliers before using. Additional sizes and shapes may be available from suppliers.
4. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

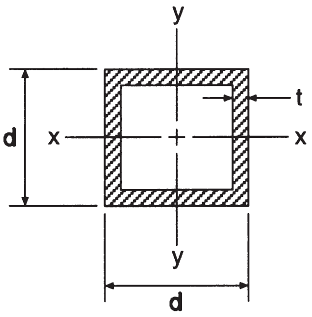


Table 23
SQUARE TUBES

					Axis x-x, y-y			
Designation	Depth width d in.	Thickness t in.	Weight lb/ft	Area A in²	I_x, I_y in⁴	S_x, S_y in³	r_x, r_y in.	J in⁴
RT 1 × 1 × .065	1.000	0.065	0.286	0.243	0.0356	0.0712	0.383	0.0531
RT 1 × 1 × .095	1.000	0.095	0.404	0.344	0.0475	0.0949	0.371	0.0704
RT 1 × 1 × .125	1.000	0.125	0.515	0.438	0.0570	0.114	0.361	0.0837
RT 1.25 × 1.25 × .065	1.250	0.065	0.362	0.308	0.0723	0.116	0.485	0.108
RT 1.25 × 1.25 × .095	1.250	0.095	0.516	0.439	0.0982	0.157	0.473	0.146
RT 1.25 × 1.25 × .125	1.250	0.125	0.662	0.563	0.120	0.192	0.462	0.178
RT 1.375 × 1.375 × .125	1.375	0.125	0.735	0.625	0.164	0.239	0.513	0.244
RT 1.5 × 1.5 × .065	1.500	0.065	0.439	0.373	0.128	0.171	0.586	0.192
RT 1.5 × 1.5 × .078	1.500	0.078	0.522	0.444	0.150	0.200	0.581	0.224
RT 1.5 × 1.5 × .095	1.500	0.095	0.628	0.534	0.176	0.235	0.575	0.263
RT 1.5 × 1.5 × .125	1.500	0.125	0.809	0.688	0.218	0.291	0.564	0.325
RT 1.5 × 1.5 × .250	1.500	0.250	1.47	1.25	0.339	0.451	0.520	0.488
RT 1.75 × 1.75 × .125	1.750	0.125	0.956	0.813	0.360	0.411	0.665	0.536
RT 2 × 2 × .095	2.000	0.095	0.851	0.724	0.439	0.439	0.779	0.657
RT 2 × 2 × .125	2.000	0.125	1.10	0.938	0.552	0.552	0.767	0.824
RT 2 × 2 × .156	2.000	0.156	1.35	1.15	0.657	0.657	0.755	0.978
RT 2 × 2 × .188	2.000	0.188	1.60	1.36	0.754	0.754	0.744	1.12
RT 2 × 2 × .250	2.000	0.250	2.06	1.75	0.911	0.911	0.722	1.34
RT 2.25 × 2.25 × .125	2.250	0.125	1.25	1.06	0.802	0.713	0.869	1.20
RT 2.5 × 2.5 × .125	2.500	0.125	1.40	1.19	1.12	0.896	0.971	1.67
RT 2.5 × 2.5 × .188	2.500	0.188	2.04	1.74	1.56	1.25	0.947	2.32
RT 2.5 × 2.5 × .250	2.500	0.250	2.65	2.25	1.92	1.54	0.924	2.85
RT 2.75 × 2.75 × .125	2.750	0.125	1.54	1.31	1.51	1.10	1.07	2.26
RT 2.75 × 2.75 × .188	2.750	0.188	2.27	1.93	2.12	1.54	1.05	3.16
RT 3 × 3 × .095	3.000	0.095	1.30	1.10	1.55	1.04	1.19	2.33
RT 3 × 3 × .125	3.000	0.125	1.69	1.44	1.98	1.32	1.17	2.97
RT 3 × 3 × .188	3.000	0.188	2.49	2.11	2.80	1.87	1.15	4.18
RT 3 × 3 × .250	3.000	0.250	3.23	2.75	3.49	2.33	1.13	5.20
RT 3 × 3 × .375	3.000	0.375	4.63	3.94	4.61	3.08	1.08	6.78
RT 3.5 × 3.5 × .125	3.500	0.125	1.98	1.69	3.21	1.83	1.38	4.81
RT 3.5 × 3.5 × .250	3.500	0.250	3.82	3.25	5.76	3.29	1.33	8.58
RT 3.5 × 3.5 × .375	3.500	0.375	5.51	4.69	7.74	4.42	1.28	11.4
RT 4 × 4 × .125	4.000	0.125	2.28	1.94	4.85	2.43	1.58	7.27
RT 4 × 4 × .188	4.000	0.188	3.37	2.87	6.96	3.48	1.56	10.4
RT 4 × 4 × .250	4.000	0.250	4.41	3.75	8.83	4.41	1.53	13.2
RT 4 × 4 × .375	4.000	0.375	6.39	5.44	12.0	6.02	1.49	17.9
RT 4 × 4 × .500	4.000	0.500	8.23	7.00	14.6	7.29	1.44	21.4

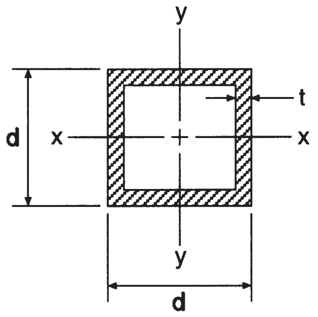


Table 23
SQUARE TUBES (Continued)

Designation	Depth width d in.	Thickness t in.	Weight lb/ft	Area A in²	Axis x-x, y-y I_x, I_y in⁴	S_x, S_y in³	r_x, r_y in.	J in⁴
RT 6 × 6 × .125	6.000	0.125	3.45	2.94	16.9	5.64	2.40	25.3
RT 6 × 6 × .188	6.000	0.188	5.14	4.37	24.6	8.21	2.37	36.9
RT 6 × 6 × .250	6.000	0.250	6.76	5.75	31.7	10.6	2.35	47.5
RT 6 × 6 × .375	6.000	0.375	9.92	8.44	44.7	14.9	2.30	66.7
RT 6 × 6 × .500	6.000	0.500	12.9	11.0	55.9	18.6	2.25	83.2
RT 8 × 8 × .188	8.000	0.188	6.91	5.87	59.8	14.9	3.19	89.6
RT 8 × 8 × .250	8.000	0.250	9.11	7.75	77.7	19.4	3.17	116
RT 8 × 8 × .375	8.000	0.375	13.5	11.4	111	27.8	3.12	166
RT 8 × 8 × .500	8.000	0.500	17.6	15.0	141	35.3	3.07	211

1. Users are encouraged to check availability with suppliers. Additional sizes and shapes may be available from suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data.*

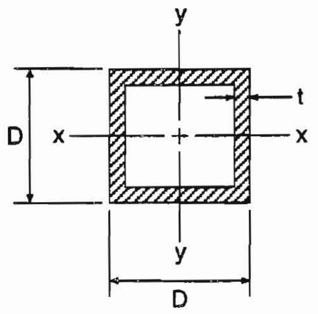


TABLE 27—SQUARE TUBE (Cont.)

The listed sizes are provided for the convenience of the designer; however, availability should be checked before making the final design selection. Additional sizes and shapes may be available from suppliers.

Note:
This page was taken from the Aluminum Design Manual, 2000. The new editions did not have the data for

3.000 SQ x 0.219

Designation			Axis x-x, y-y			
D SQ × t Wall in. in.	Weight lb/ft	Area in.^{2}	I_x, I_y in.^{4}	S_x, S_y in.^{3}	r_x, r_y in.	J in.^{4}
1.375 SQ × .035 Wall	0.221	0.188	0.0562	0.0817	0.547	0.0842
1.375 SQ × .049 Wall	0.306	0.260	0.0763	0.111	0.542	0.114
1.375 SQ × .058 Wall	0.359	0.306	0.0885	0.129	0.538	0.132
1.375 SQ × .065 Wall	0.401	0.341	0.0977	0.142	0.535	0.146
1.375 SQ × .083 Wall	0.504	0.429	0.120	0.174	0.529	0.179
1.375 SQ × .095 Wall	0.572	0.486	0.134	0.194	0.524	0.199
1.500 SQ × .035 Wall	0.241	0.205	0.0734	0.0979	0.598	0.110
1.500 SQ × .049 Wall	0.334	0.284	0.0999	0.133	0.593	0.150
1.500 SQ × .058 Wall	0.393	0.335	0.116	0.155	0.589	0.174
1.500 SQ × .065 Wall	0.439	0.373	0.128	0.171	0.586	0.192
1.500 SQ × .083 Wall	0.553	0.470	0.158	0.211	0.579	0.236
1.500 SQ × .095 Wall	0.628	0.534	0.176	0.235	0.575	0.263
1.750 SQ × .049 Wall	0.392	0.333	0.161	0.184	0.695	0.241
1.750 SQ × .058 Wall	0.462	0.393	0.188	0.214	0.691	0.281
1.750 SQ × .065 Wall	0.515	0.438	0.208	0.237	0.688	0.311
1.750 SQ × .083 Wall	0.651	0.553	0.257	0.294	0.681	0.384
1.750 SQ × .095 Wall	0.740	0.629	0.288	0.329	0.677	0.431
1.750 SQ × .120 Wall	0.920	0.782	0.348	0.398	0.667	0.520
2.000 SQ × .049 Wall	0.450	0.382	0.243	0.243	0.797	0.364
2.000 SQ × .058 Wall	0.530	0.451	0.283	0.283	0.793	0.425
2.000 SQ × .065 Wall	0.592	0.503	0.314	0.314	0.790	0.471
2.000 SQ × .083 Wall	0.748	0.636	0.391	0.391	0.783	0.585
2.000 SQ × .095 Wall	0.851	0.724	0.439	0.439	0.779	0.657
2.000 SQ × .120 Wall	1.06	0.902	0.534	0.534	0.769	0.797
2.250 SQ × .049 Wall	0.507	0.431	0.348	0.310	0.899	0.522
2.250 SQ × .058 Wall	0.598	0.509	0.408	0.362	0.895	0.611
2.250 SQ × .065 Wall	0.668	0.568	0.452	0.402	0.892	0.678
2.250 SQ × .083 Wall	0.846	0.719	0.564	0.501	0.885	0.845
2.250 SQ × .095 Wall	0.963	0.819	0.635	0.565	0.881	0.951
2.250 SQ × .120 Wall	1.20	1.20	0.776	0.689	0.871	1.16
2.500 SQ × .058 Wall	0.666	0.567	0.563	0.451	0.997	0.845
2.500 SQ × .065 Wall	0.745	0.633	0.626	0.501	0.994	0.938
2.500 SQ × .083 Wall	0.944	0.802	0.782	0.626	0.987	1.17
2.500 SQ × .095 Wall	1.07	0.914	0.882	0.706	0.983	1.32
2.500 SQ × .120 Wall	1.34	1.14	1.08	0.865	0.973	1.62
2.500 SQ × .156 Wall	1.72	1.46	1.35	1.08	0.959	2.01
2.750 SQ × .058 Wall	0.734	0.625	0.755	0.549	1.10	1.13
2.750 SQ × .065 Wall	0.821	0.698	0.839	0.610	1.10	1.26
2.750 SQ × .083 Wall	1.04	0.885	1.05	0.764	1.09	1.57
2.750 SQ × .095 Wall	1.19	1.01	1.19	0.863	1.08	1.78
2.750 SQ × .120 Wall	1.48	1.26	1.46	1.06	1.07	2.18
2.750 SQ × .156 Wall	1.90	1.62	1.82	1.32	1.06	2.72
2.750 SQ × .188 Wall	2.27	1.93	2.12	1.54	1.05	3.16
3.000 SQ × .065 Wall	0.897	0.763	1.10	0.731	1.20	1.64
3.000 SQ × .083 Wall	1.14	0.968	1.37	0.916	1.19	2.06
3.000 SQ × .095 Wall	1.30	1.10	1.55	1.04	1.19	2.33
3.000 SQ × .120 Wall	1.63	1.38	1.91	1.28	1.18	2.87
3.000 SQ × .156 Wall	2.09	1.77	2.40	1.60	1.16	3.59
3.000 SQ × .188 Wall	2.49	2.11	2.80	1.87	1.15	4.18
3.000 SQ × .219 Wall	2.86	2.44	3.16	2.11	1.14	4.71

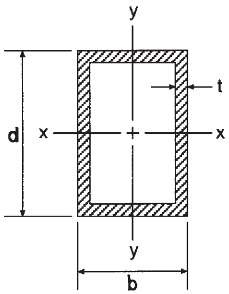


Table 24
RECTANGULAR TUBES

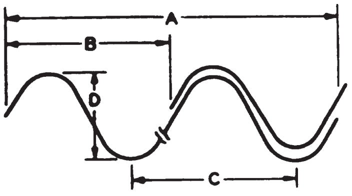
Designation	Width b in.	Depth d in.	Thickness t in.	Weight lb/ft	Area A in^2	Axis x-x			Axis y-y			J in^4
						I_x in^4	S_x in^3	r_x in.	I_y in^4	S_y in^3	r_y in.	
RT 1 × 1 1/2 × 1/8	1.000	1.500	0.125	0.662	0.563	0.159	0.212	0.532	0.0811	0.162	0.380	0.161
RT 1 × 2 × 1/8	1.000	2.000	0.125	0.809	0.688	0.332	0.332	0.695	0.105	0.210	0.391	0.245
RT 1 × 2 1/2 × 1/8	1.000	2.500	0.125	0.956	0.813	0.590	0.472	0.852	0.129	0.258	0.399	0.332
RT 1 × 3 × 1/8	1.000	3.000	0.125	1.10	0.938	0.950	0.633	1.01	0.153	0.307	0.404	0.422
RT 1 × 4 × 1/8	1.000	4.000	0.125	1.40	1.19	2.04	1.02	1.31	0.201	0.403	0.412	0.605
RT 1 1/4 × 2 × 1/8	1.250	2.000	0.125	0.882	0.750	0.387	0.387	0.718	0.180	0.288	0.489	0.371
RT 1 1/4 × 2 1/2 × 1/8	1.250	2.500	0.125	1.03	0.875	0.678	0.543	0.881	0.219	0.351	0.501	0.510
RT 1 1/4 × 3 × 1/8	1.250	3.000	0.125	1.18	1.00	1.08	0.720	1.04	0.259	0.415	0.509	0.654
RT 1 1/2 × 1 3/4 × 1/8	1.500	1.750	0.125	0.882	0.750	0.318	0.364	0.652	0.248	0.331	0.575	0.416
RT 1 1/2 × 2 × 1/8	1.500	2.000	0.125	0.956	0.813	0.442	0.442	0.737	0.278	0.370	0.585	0.511
RT 1 1/2 × 2 × 1/4	1.500	2.000	0.250	1.76	1.50	0.719	0.719	0.692	0.438	0.583	0.540	0.798
RT 1 1/2 × 2 1/2 × 1/8	1.500	2.500	0.125	1.10	0.938	0.767	0.613	0.904	0.337	0.449	0.599	0.711
RT 1 1/2 × 3 × 1/8	1.500	3.000	0.125	1.25	1.06	1.21	0.806	1.07	0.396	0.528	0.611	0.919
RT 1 1/2 × 3 × 3/16	1.500	3.000	0.188	1.82	1.55	1.68	1.12	1.04	0.533	0.711	0.586	1.24
RT 1 1/2 × 4 × 1/8	1.500	4.000	0.125	1.54	1.31	2.51	1.25	1.38	0.515	0.686	0.626	1.35
RT 1 1/2 × 6 × 1/8	1.500	6.000	0.125	2.13	1.81	7.20	2.40	1.99	0.752	1.00	0.644	2.25
RT 1 3/4 × 2 × 1/8	1.750	2.000	0.125	1.03	0.875	0.497	0.497	0.753	0.401	0.458	0.677	0.663
RT 1 3/4 × 2 1/4 × 1/8	1.750	2.250	0.125	1.10	0.938	0.661	0.588	0.840	0.442	0.506	0.687	0.795
RT 1 3/4 × 2 1/2 × 1/8	1.750	2.500	0.125	1.18	1.00	0.855	0.684	0.925	0.484	0.553	0.696	0.931
RT 1 3/4 × 2 3/4 × 1/8	1.750	2.750	0.125	1.25	1.06	1.08	0.785	1.01	0.525	0.600	0.703	1.07
RT 1 3/4 × 3 × 1/8	1.750	3.000	0.125	1.32	1.13	1.34	0.892	1.09	0.566	0.647	0.710	1.21
RT 1 3/4 × 3 1/2 × 1/8	1.750	3.500	0.125	1.47	1.25	1.96	1.12	1.25	0.649	0.742	0.721	1.50
RT 1 3/4 × 4 × 1/8	1.750	4.000	0.125	1.62	1.38	2.74	1.37	1.41	0.732	0.836	0.730	1.80
RT 1 3/4 × 4 1/2 × 1/8	1.750	4.500	0.125	1.76	1.50	3.69	1.64	1.57	0.814	0.931	0.737	2.11
RT 1 3/4 × 5 × 1/8	1.750	5.000	0.125	1.91	1.63	4.83	1.93	1.72	0.897	1.03	0.743	2.41
RT 1 3/4 × 5 × 3/16	1.750	5.000	0.188	2.82	2.40	6.91	2.76	1.70	1.23	1.41	0.717	3.33
RT 1 3/4 × 6 × 1/8	1.750	6.000	0.125	2.21	1.88	7.74	2.58	2.03	1.06	1.21	0.753	3.04

Designation	Width b in.	Depth d in.	Thickness t in.	Weight lb/ft	Area A in^2	Axis x-x			Axis y-y			J in^4
						I_x in^4	S_x in^3	r_x in.	I_y in^4	S_y in^3	r_y in.	
RT 2 × 3 × 1/8	2.000	3.000	0.125	1.40	1.19	1.47	0.978	1.11	0.772	0.77	0.806	1.53
RT 2 × 3 × 1/4	2.000	3.000	0.250	2.65	2.25	2.55	1.70	1.06	1.30	1.30	0.759	2.57
RT 2 × 4 × 1/8	2.000	4.000	0.125	1.69	1.44	2.98	1.49	1.44	0.992	0.992	0.831	2.30
RT 2 × 4 × 3/16	2.000	4.000	0.188	2.49	2.11	4.23	2.11	1.41	1.37	1.37	0.806	3.19
RT 2 × 4 × 1/4	2.000	4.000	0.250	3.23	2.75	5.31	2.65	1.39	1.68	1.68	0.782	3.92
RT 2 × 5 × 1/8	2.000	5.000	0.125	1.98	1.69	5.20	2.08	1.76	1.21	1.21	0.847	3.09
RT 2 × 5 × 3/16	2.000	5.000	0.188	2.93	2.49	7.45	2.98	1.73	1.68	1.68	0.822	4.32
RT 2 × 5 × 1/4	2.000	5.000	0.250	3.82	3.25	9.44	3.78	1.70	2.07	2.07	0.798	5.32
RT 2 × 6 × 1/8	2.000	6.000	0.125	2.28	1.94	8.28	2.76	2.07	1.43	1.43	0.860	3.91
RT 2 × 6 × 3/16	2.000	6.000	0.188	3.37	2.87	11.9	3.98	2.04	1.99	1.99	0.834	5.47
RT 2 × 6 × 1/4	2.000	6.000	0.250	4.41	3.75	15.2	5.07	2.01	2.45	2.45	0.809	6.75
RT 2 × 8 × 1/8	2.000	8.000	0.125	2.87	2.44	17.5	4.36	2.68	1.87	1.87	0.876	5.59
RT 2 1/2 × 4 × 1/8	2.500	4.000	0.125	1.84	1.56	3.45	1.72	1.48	1.65	1.32	1.03	3.39
RT 2 1/2 × 5 × 1/8	2.500	5.000	0.125	2.13	1.81	5.95	2.38	1.81	2.00	1.60	1.05	4.62
RT 3 × 4 × 1/8	3.000	4.000	0.125	1.98	1.69	3.92	1.96	1.52	2.50	1.67	1.22	4.60
RT 3 × 4 × 3/16	3.000	4.000	0.188	2.93	2.49	5.59	2.80	1.50	3.54	2.36	1.19	6.52
RT 3 × 4 × 1/4	3.000	4.000	0.250	3.82	3.25	7.07	3.53	1.47	4.44	2.96	1.17	8.18
RT 3 × 4 × 3/8	3.000	4.000	0.375	5.51	4.69	9.56	4.78	1.43	5.92	3.94	1.12	10.9
RT 3 × 4 × 1/2	3.000	4.000	0.500	7.06	6.00	11.5	5.75	1.38	7.00	4.67	1.08	12.8
RT 3 × 5 × 1/8	3.000	5.000	0.125	2.28	1.94	6.69	2.68	1.86	3.02	2.01	1.25	6.34
RT 3 × 5 × 3/16	3.000	5.000	0.188	3.37	2.87	9.63	3.85	1.83	4.29	2.86	1.22	9.03
RT 3 × 5 × 1/4	3.000	5.000	0.250	4.41	3.75	12.3	4.91	1.81	5.39	3.59	1.20	11.4
RT 3 × 6 × 1/8	3.000	6.000	0.125	2.57	2.19	10.4	3.48	2.18	3.53	2.36	1.27	8.15
RT 3 × 6 × 3/16	3.000	6.000	0.188	3.81	3.24	15.1	5.03	2.16	5.03	3.35	1.25	11.6
RT 3 × 8 × 1/4	3.000	8.000	0.250	6.17	5.25	40.1	10.0	2.76	8.23	5.49	1.25	21.6
RT 4 × 5 × 1/4	4.000	5.000	0.250	5.00	4.25	15.1	6.04	1.88	10.6	5.29	1.58	18.7
RT 4 × 6 × 1/8	4.000	6.000	0.125	2.87	2.44	12.6	4.20	2.27	6.73	3.37	1.66	13.3
RT 4 × 6 × 3/16	4.000	6.000	0.188	4.26	3.62	18.3	6.09	2.25	9.69	4.85	1.64	19.2
RT 4 × 6 × 1/4	4.000	6.000	0.250	5.59	4.75	23.5	7.82	2.22	12.3	6.17	1.61	24.5
RT 4 × 6 × 1/2	4.000	6.000	0.500	10.6	9.00	40.8	13.6	2.13	20.8	10.4	1.52	41.2
RT 4 × 8 × 3/16	4.000	8.000	0.188	5.14	4.37	36.8	9.21	2.90	12.4	6.21	1.69	28.7
RT 4 × 8 × 1/4	4.000	8.000	0.250	6.76	5.75	47.6	11.9	2.88	15.9	7.93	1.66	36.7
RT 4 × 8 × 3/8	4.000	8.000	0.375	9.92	8.44	67.5	16.9	2.83	21.9	11.0	1.61	50.9
RT 4 × 8 × 1/2	4.000	8.000	0.500	12.9	11.0	84.9	21.2	2.78	26.9	13.5	1.56	62.6
RT 5 × 8 × 3/8	5.000	8.000	0.375	10.8	9.19	78.4	19.6	2.92	37.0	14.8	2.01	76.1

1. Users are encouraged to check availability with suppliers. Additional sizes and shapes may be available from suppliers.
2. Tolerances for extruded shapes are given in *Aluminum Standards and Data*.

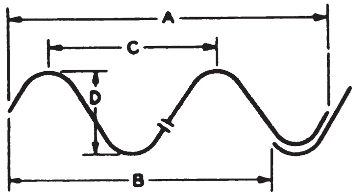
Table 25
ROOFING AND SIDING – DIMENSIONS AND WEIGHTS

Corrugated Roofing



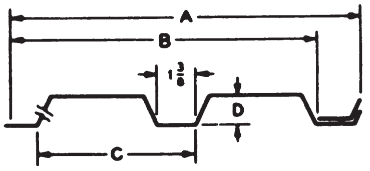
Nominal Thickness[1] in.	Nominal Over-All Width in.	Nominal Coverage Width[2] in.	Nominal Pitch of Corrugation in.	Nominal Depth of Corrugation[3] in.	Nominal Weight Per 100 Sq Ft[4] lb
	Dim. A	Dim. B	Dim. C	Dim. D	
0.024	35	32	2⅔	⅞	41
0.024	48⅓	45⅓	2⅔	⅞	41
0.032	35	32	2⅔	⅞	55
0.032	48⅓	45⅓	2⅔	⅞	55
0.032	48⅜	45⅜	2⅔	⅞	55
0.040	48⅓	45⅓	2⅔	⅞	69

Corrugated Siding



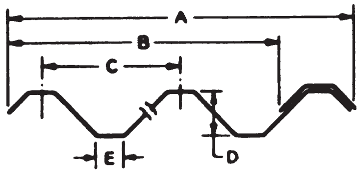
Nominal Thickness[1] in.	Nominal Over-All Width in.	Nominal Coverage Width[2] in.	Nominal Pitch of Corrugation in.	Nominal Depth of Corrugation[3] in.	Nominal Weight Per 100 Sq Ft[4] lb
0.024	33¾	32	2⅔	⅞	41
0.024	47	45⅓	2⅔	⅞	41
0.032	33¾	32	2⅔	⅞	55
0.032	47	45⅓	2⅔	⅞	55
0.032	47⅛	45⅜	2⅔	⅞	55

Ribbed Siding



Nominal Thickness[1] in.	Nominal Over-All Width in.	Nominal Coverage Width[2] in.	Nominal Pitch of Corrugation in.	Nominal Depth of Corrugation[3] in.	Nominal Weight Per 100 Sq Ft[4] lb
0.032	41⅝	40 (see note 6)	4	1	58
0.032	41⅝	40 (see note 6)	8	1	52
0.040	41⅝	40 (see note 6)	4	1	73
0.040	41⅝	40 (see note 6)	8	1	65

V-Beam Roofing and Siding



Nominal Thickness[1] in.	Nominal Over-All Width in.	Nominal Coverage Width[5] in.	Nominal Pitch of Corrugation in.	Nominal Depth of Corrugation[3] in.	Nominal Width of Crown and Valley in.	Nominal Weight Per 100 Sq Ft[4] lb
	Dim. A	Dim B	Dim. C	Dim. D	Dim. E	
0.032	41⅝	39	4⅞	1¾	¾	58
0.032	45	42⅔	5⅓	1¾	1⅛	58
0.040	41⅝	39	4⅞	1¾	¾	73
0.040	45	42⅔	5⅓	1¾	1⅛	73
0.050	41⅝	39	4⅞	1¾	¾	91
0.050	45	42⅔	5⅓	1¾	1⅛	91

[1] Applicable to flat sheet prior to corrugating or embossing.
[2] Based on 1½ corrugations side lap.
[3] As measured between the outside surfaces of adjacent corrugations.
[4] Based on over-all width of formed sheet.
[5] Based on one corrugation side lap.
[6] Based on side lap of 1⅝ in.

Table 26
ROOFING AND SIDING – SECTION PROPERTIES

	Thickness, in.	Weight, lb/ft²	Area, in.² per ft of width	Moment of Inertia, in.⁴ per ft of width	Minimum Section Modulus, in.³ per ft of width	Maximum Section Modulus, in.³ per ft of width	Radius of Gyration, in.
Corrugated Roofing and Siding	0.024	0.414	0.352	0.0307	0.0708	0.0708	0.295
	0.032	0.552	0.469	0.0409	0.0936	0.0936	0.295
	0.040	0.689	0.586	0.0512	0.116	0.116	0.295
Ribbed Siding, 4″ Pitch	0.032	0.585	0.497	0.0836	0.160	0.175	0.410
	0.040	0.730	0.621	0.104	0.198	0.217	0.410
Ribbed Siding, 8″ Pitch	0.032	0.518	0.441	0.0648	0.0895	0.235	0.383
	0.040	0.648	0.551	0.0810	0.111	0.289	0.383
V-Beam Roofing and Siding, 4⅞″ Pitch	0.032	0.584	0.497	0.179	0.205	0.205	0.600
	0.040	0.730	0.621	0.223	0.255	0.255	0.600
	0.050	0.913	0.776	0.279	0.317	0.317	0.600
V-Beam Roofing and Siding, 5⅓″ Pitch	0.032	0.581	0.494	0.199	0.229	0.229	0.635
	0.040	0.726	0.617	0.249	0.285	0.285	0.635
	0.050	0.907	0.771	0.311	0.354	0.354	0.635

*Calculated on basis of nominal dimensions (See Table 25)

Table 27
DECIMAL EQUIVALENTS IN INCHES OF SHEET METAL AND WIRE GAUGES

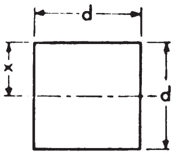
NAME OF GAGE	American or Browne & Sharpe	United States Standard	Manufacturers Standard†	British Imperial Standard	Birmingham or Stubs Iron Wire	Stubs Steel Wire	Steel Wire or Washburn & Moen
Abbrev	B & S	U.S. Std.		S. W. G.	B. W. G.		
PRINCIPAL USE	Alluminum, Non-Ferrous Sheet, Wire and Rod	Steel Sheet and Plate (480 lb/ft^3)	Ferrous Sheet	Wire, Rod, Sheet and Plate (British)	Tube, Ferrous Strip and Flat Wire, Spring Steel	Steel Drill Rod	Ferrous Wire Except Music Wire
No.*	Thickness or diameter—in.						
7/0's	-----	0.500	-----	0.500	-----	-----	0.4900
6/0's	0.5800	.46875	-----	.464	-----	-----	.4615
5/0's	.5165	.4375	-----	.432	-----	-----	.4305
4/0's	.4600	.40625	-----	.400	0.454	-----	.3938
3/0's	.4096	.375	-----	.372	.425	-----	.3625
2/0's	.3648	.34375	-----	.348	.380	-----	.3310
0	.3249	.3125	-----	.324	.340	-----	.3065
1	.2893	.28125	-----	.300	.300	0.227	.2830
2	.2576	.265625	-----	.276	.284	.219	.2625
3	.2294	.25	0.2391	.252	.259	.212	.2437
4	.2043	.234375	.2242	.232	.238	.207	.2253
5	.1819	.21875	.2092	.212	.220	.204	.2070
6	.1620	.203125	.1943	.192	.203	.201	.1920
7	.1443	.1875	.1793	.176	.180	.199	.1770
8	.1285	.171875	.1644	.160	.165	.197	.1620
9	.1144	.15625	.1495	.144	.148	.194	.1483
10	.1019	.140625	.1345	.128	.134	.191	.1350
11	.09074	.125	.1196	.116	.120	.188	.1205
12	.08081	.109375	.1046	.104	.109	.185	.1055
13	.07196	.09375	.0897	.092	.095	.182	.0915
14	.06408	.078125	.0747	.080	.083	.180	.0800
15	.05707	.0703125	.0673	.072	.072	.178	.0720
16	.05082	.0625	.0598	.064	.065	.175	.0625
17	.04526	.05625	.0538	.056	.058	.172	.0540
18	.04030	.05	.0478	.048	.049	.168	.0475
19	.03589	.04375	.0418	.040	.042	.164	.0410
20	.03196	.0375	.0359	.036	.035	.161	.0348
21	.02846	.034375	.0329	.032	.032	.157	.03175
22	.02535	.03125	.0299	.028	.028	.155	.0286
23	.02257	.028125	.0269	.024	.025	.153	.0258
24	.02010	.025	.0239	.022	.022	.151	.0230
25	.01790	.021875	.0209	.020	.020	.148	.0204
26	.01594	.01875	.0179	.018	.018	.146	.0181
27	.01420	.0171875	.0164	.0164	.016	.143	.0173
28	.01264	.015625	.0149	.0148	.014	.139	.0162
29	.01126	.0140625	.0135	.0136	.013	.134	.0150
30	.01003	.0125	.0120	.0124	.012	.127	.0140
31	.008928	.0109375	.0105	.0116	.010	.120	.0132
32	.007950	.01015625	.0097	.0108	.009	.115	.0128
33	.007080	.009375	.0090	.0100	.008	.112	.0118
34	.006305	.00859375	.0082	.0092	.007	.110	.0104
35	.005615	.0078125	.0075	.0084	.005	.108	.0095
36	.005000	.00703125	.0067	.0076	.004	.106	.0090
37	.004453	.006640625	.0064	.0068		.103	.0085
38	.003965	.00625	.0060	.0060		.101	.0080
39	.003531			.0052		.099	.0075
40	.003145			.0048		.097	.0070

* Designation of size in decimal of an inch instead of gage number is recommended. If gage number is used, the name of the gage must be specified.

† Adopted by the American Iron and Steel Institute as a modification of United States Standard Gage to reflect present average unit weights of sheet steel.

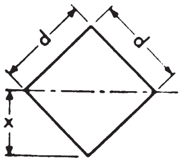
Table 28
GEOMETRIC SHAPES

SQUARE



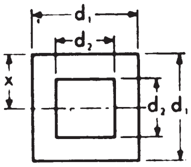
$$A = d^2$$
$$x = \frac{d}{2}$$
$$I = \frac{d^4}{12}$$
$$S = \frac{d^3}{6}$$
$$r = \frac{d}{\sqrt{12}} = 0.2887d$$

SQUARE



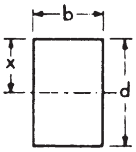
$$A = d^2$$
$$x = \frac{d}{\sqrt{2}} = 0.7071d$$
$$I = \frac{d^4}{12}$$
$$S = \frac{\sqrt{2}d^3}{12} = 0.1179d^3$$
$$r = \frac{d}{\sqrt{12}} = 0.2887d$$

HOLLOW SQUARE



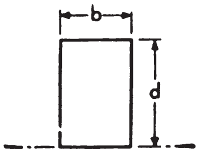
$$A = d_1^2 - d_2^2$$
$$x = \frac{d_1}{2}$$
$$I = \frac{d_1^4 - d_2^4}{12}$$
$$S = \frac{d_1^4 - d_2^4}{6d_1}$$
$$r = \sqrt{\frac{d_1^2 + d_2^2}{12}}$$

RECTANGLE



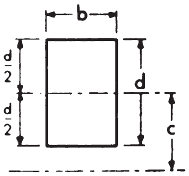
$$A = bd$$
$$x = \frac{d}{2}$$
$$I = \frac{bd^3}{12}$$
$$S = \frac{bd^2}{6}$$
$$r = \frac{d}{\sqrt{12}} = 0.2887d$$

RECTANGLE



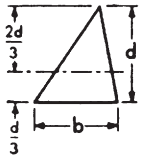
$$A = bd$$
$$I = \frac{bd^3}{3}$$

RECTANGLE



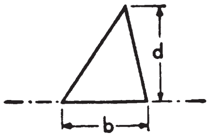
$$A = bd$$
$$I = A\left(\frac{d^2}{12} + c^2\right)$$

TRIANGLE



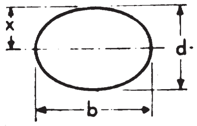
$$A = \frac{bd}{2}$$
$$I = \frac{bd^3}{36}$$
$$r = \frac{d}{\sqrt{18}} = 0.2357d$$

TRIANGLE



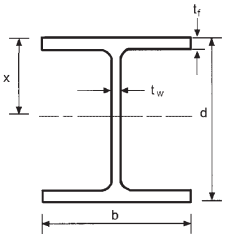
$$A = \frac{bd}{2}$$
$$I = \frac{bd^3}{12}$$

ELLIPSE



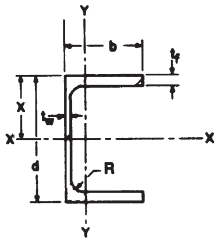
$$A = \frac{\pi bd}{4}$$
$$I = \frac{\pi bd^3}{64}$$
$$S = \frac{\pi bd^2}{32}$$
$$r = \frac{d}{4}$$
$$x = \frac{d}{2}$$

I-BEAM



$$A = 2bt_f + (d - 2t_f)t_w$$
$$x = d/2$$
$$I = \frac{t_w}{12}(d - 2t_f)^3 + 2\left[\frac{bt_f^3}{12} + bt_f\left(\frac{d - t_f}{2}\right)^2\right]$$
$$J = [2bt_f^3 + (d - 2t_f)t_w^3]/3$$
$$C_w = \frac{t_f(d - t_f)^2 b^3}{24}$$

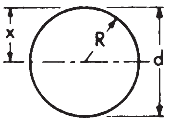
CHANNEL



$$A = 2bt_f + (d - 2t_f)t_w$$
$$x = d/2$$
$$I = \frac{t_w}{12}(d - 2t_f)^3 + 2\left[\frac{bt_f^3}{12} + bt_f\left(\frac{d - t_f}{2}\right)^2\right]$$
$$J = [2bt_f^3 + (d - 2t_f)t_w^3]/3$$
$$C_w = \frac{t_f b^3 (d - t_f)^2 (3bt_f + 2t_w(d - t_f))}{12(6bt_f + (d - t_f)t_w)}$$

Table 28
GEOMETRIC SHAPES (Continued)

CIRCLE



$$A = \pi R^2 = \frac{\pi d^2}{4}$$

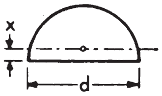
$$I = \frac{\pi R^4}{4} = \frac{\pi d^4}{64}$$

$$S = \frac{\pi R^3}{4} = \frac{\pi d^3}{32}$$

$$r = \frac{R}{2} = \frac{d}{4}$$

$$x = R = \frac{d}{2}$$

HALF CIRCLE

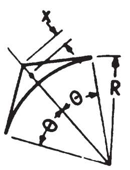


$$A = \frac{\pi R^2}{2} = \frac{\pi d^2}{8}$$

$$I = 0.1098R^4 = 0.0069d^4$$

$$x = \frac{4R}{3\pi} = \frac{2d}{3\pi}$$

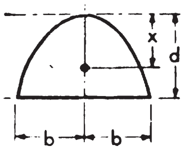
CIRCULAR FILLET



$$A = (\tan\theta - \theta)R^2$$

$$x = \left(\sec\theta - \frac{\tan^2\theta\sin\theta}{3(\tan\theta - \theta)}\right)R$$

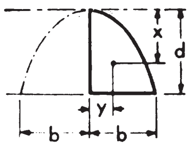
PARABOLA



$$A = \frac{4bd}{3}$$

$$x = \frac{6d}{10}$$

HALF PARABOLA

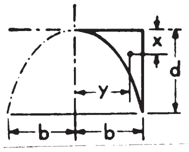


$$A = \frac{2bd}{3}$$

$$I = \frac{6d}{10}$$

$$y = \frac{3b}{8}$$

COMPLEMENT OF HALF PARABOLA

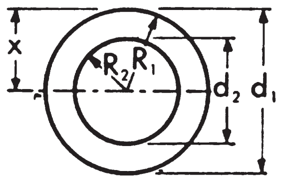


$$A = \frac{bd}{3}$$

$$x = \frac{3d}{10}$$

$$y = \frac{3b}{4}$$

HOLLOW CIRCLE



$$A = \pi(R_1^2 - R_2^2) = \frac{\pi(d_1^2 - d_2^2)}{4}$$

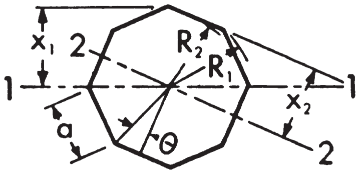
$$x = R_1 = \frac{d_1}{2}$$

$$I = \frac{\pi(R_1^4 - R_2^4)}{4} = \frac{\pi(d_1^4 - d_2^4)}{64}$$

$$S = \frac{\pi(R_1^4 - R_2^4)}{4R_1} = \frac{\pi(d_1^4 - d_2^4)}{32d_1}$$

$$r = \sqrt{\frac{R_1^2 + R_2^2}{4}} = \sqrt{\frac{d_1^2 + d_2^2}{16}}$$

REGULAR POLYGON



n = Number of Sides

$a = 2\sqrt{R_1^2 - R_2^2}$, $\theta = \frac{180°}{n}$

$$A = \frac{na^2\cot\theta}{4} = \frac{nR_1^2\sin 2\theta}{2} = nR_2^2\tan\theta$$

$$x_1 = R_1 = \frac{a}{2\sin\theta}, \qquad x_2 = R = \frac{a}{2\tan\theta}$$

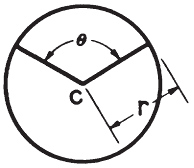
$$\times_{1-1} = I_{2-2} = \frac{A(6R_1^2 - a^2)}{24} = \frac{A(12R_2^2 + a^2)}{48}$$

$$S_{1-1} = \frac{A(6R_1^2 - a^2)}{24R_1}, \qquad S_{2-2} = \frac{A(12R_2^2 + a^2)}{48R_2}$$

$$r_{1-1} = \sqrt{\frac{6R_1^2 - a^2}{24}}, \qquad r_{2-2} = \sqrt{\frac{12R_2^2 + a^2}{48}}$$

Table 28
GEOMETRIC SHAPES (Continued)

CIRCULAR SECTOR



Area of sector $= \frac{1}{2}(\text{length of arc} \times r)$

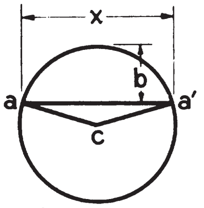
$= \text{Area of circle} \times \frac{\theta}{360}$

$= 0.0087266 \times r^2 \times \theta$

$r =$ radius of circle

$\theta =$ sector angle in degrees

CIRCULAR SEGMENT



Area of top segment =

Area of top sector − Area of triangle $aa'c$ =

$$\frac{(\text{Length of top arc} \times r) - x(r - b)}{2}.$$

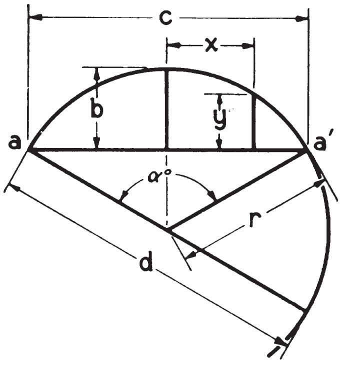
$r =$ radius of circle

$x =$ chord $b =$ rise

Area of bottom segment = Area of circle − Area of top segment

---

PROPERTIES OF THE CIRCLE



Circumference $= 6.28318r = 3.14159d$

Diameter $= 0.31834$ circumference

Area $= 3.14159r^2$

$$\text{Arc } aa' = \frac{\pi r\alpha^\circ}{180^\circ} = 0.017453r\alpha^\circ$$

$$\text{Angle } \alpha^\circ = \frac{180^\circ}{\pi r}aa' = 57.29578\frac{aa'}{r}$$

$$\text{Radius } r = \frac{4b^2 + c^2}{8b}$$

$$\text{Chord } c = 2\sqrt{2br - b^2} = 2r\sin\frac{\alpha}{2}$$

$$\text{Rise } b = r - \tfrac{1}{2}\sqrt{4r^2 - c^2} = \frac{c}{2}\tan\frac{\alpha}{4}$$

$$= 2r\sin^2\frac{\alpha}{4} = r + y - \sqrt{r^2 - x^2}$$

$$y = b - r + \sqrt{r^2 - x^2}$$

$$x = \sqrt{r^2 - (r + y - b)^2}$$

FUNCTIONS OF π

$\pi = 3.14159265359$, log $= 0.4971499$

$x^2 = 9.8696044$, log $= 0.9942997$

$\pi^3 = 31.0062767$, log $= 1.4914496$

$\sqrt{\pi} = 1.7724539$, log $= 0.2485749$

$\frac{1}{\pi} = 0.3183099$, log $= 1.5028501$

$\frac{1}{\pi^2} = 0.1013212$, log $= 1.0057003$

$\frac{1}{\pi^3} = 0.0322515$, log $= 2.5085500$

$\sqrt{\frac{1}{\pi}} = 0.5641896$, log $= 1.7514251$

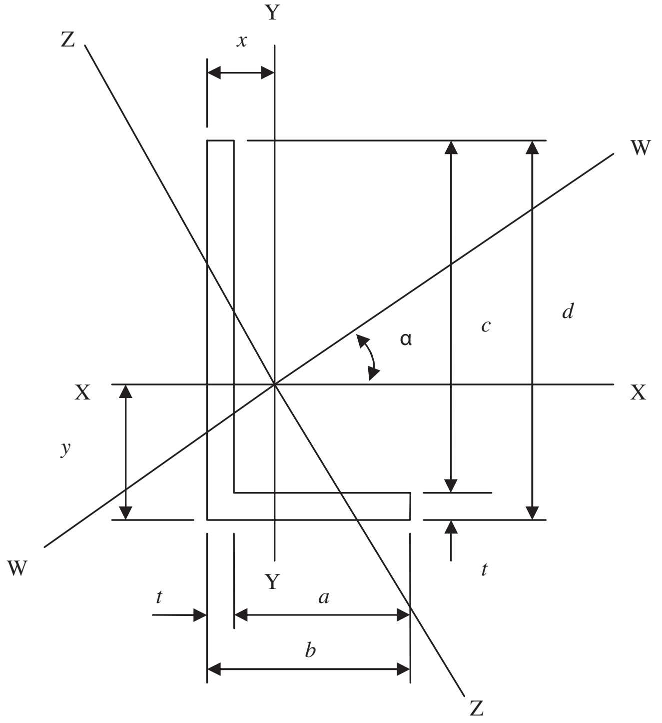
$\frac{\pi}{180} = 0.0174533$, log $= 2.2418774$

$\frac{180}{\pi} = 57.2957795$, log $= 1.7581226$

Diameter of circle of equal periphery as square = 1.27324 side of square
Side of square of equal periphery as circle = 0.78540 diameter of circle
Diameter of circle circumscribed about square = 1.41421 side of square
Side of square inscribed in circle = 0.70711 diameter of circle

Table 28
GEOMETRIC SHAPES (Continued)

ANGLE



z-z axis is axis of minimum I

$$x = \frac{b^2 + ct}{2(b+c)} \qquad y = \frac{d^2 + at}{2(b+c)}$$

$$I_x = \frac{t(d-y)^3 + by^3 - a(y-t)^3}{3} \qquad I_y = \frac{t(b-x)^3 + dx^3 - c(x-t)^3}{3}$$

$$K = \frac{abcdt}{4(b+c)} \qquad \alpha = (1/2)\tan^{-1}\left(\frac{2K}{I_y - I_x}\right)$$

$$I_z = I_x \sin^2 \alpha + I_y \cos^2 \alpha + K \sin 2\alpha$$

$$I_x + I_y = I_w + I_z$$

$$I_w = I_x \cos^2 \alpha + I_y \sin^2 \alpha - K \sin 2\alpha$$

$$x_o = x - t/2 \qquad y_o = y - t/2$$

$$w_o = y_o \sin\alpha + x_o \cos\alpha \qquad z_o = y_o \cos\alpha - x_o \sin\alpha$$

$$b' = d - t/2 \qquad d' = b - t/2$$

$$C_1 = \frac{x_o^{\,2}}{2}\left[y_o^{\,2} - (y_o - b')^2\right] + \frac{\left(y_o^{\,4} - (y_o - b')^4\right)}{4} + \frac{y_o}{3}\left[x_o^{\,3} - (x_o - d')^3\right] + y_o^{\,3} d'$$

$$C_2 = \frac{y_o^{\,2}}{2}\left[x_o^{\,2} - (x_o - d')^2\right] + \frac{\left(x_o^{\,4} - (x_o - d')^4\right)}{4} + \frac{x_o}{3}\left[y_o^{\,3} - (y_o - b')^3\right] + x_o^{\,3} b'$$

$$\beta_w = \frac{t(C_1 \cos\alpha - C_2 \sin\alpha)}{I_w} - 2z_o$$

Aluminum Design Manual

PART VI

Design Aids

VI
Design Aids

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Buckling Constants

Allowable Stresses for Building-Type Structures

Bending

Allowable Loads

Fasteners

Welds

Table 1-1
BUCKLING CONSTANTS (UNWELDED)

Alloy	Temper	Product*	Thickness in.	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
1100	H12	Sheet, Plate, Drawn Tube, Rod & Bar	All	11.0	0.044	165	12.8	0.056	153	12.7	0.372	573	17.0	0.086	133	19.1	0.875	160	8.6	0.031	187
	H14	Sheet, Plate, Drawn Tube, Rod & Bar	All	14.5	0.067	144	17.0	0.086	133	16.8	0.536	446	22.6	0.131	115	25.1	1.261	133	11.1	0.045	164
2014	T6	Sheet	0.040 to 0.249	68.6	0.544	52	79.1	0.673	48	74.3	3.132	94	119.5	1.532	52	111.5	8.962	41	53.1	0.370	59
	T651	Plate	0.250 to 2.000	67.3	0.529	52	77.6	0.655	49	73.0	3.058	95	117.2	1.489	52	109.5	8.752	41	47.9	0.318	62
	T6, T6510, T6511	Extrusions	All	59.9	0.444	55	69.0	0.548	52	65.2	2.628	105	103.8	1.240	56	97.7	7.521	44	42.7	0.267	66
	T6, T651	Rod & Bar, Drawn Tube	All	61.1	0.458	55	70.4	0.566	51	66.5	2.699	103	106.0	1.280	55	99.7	7.723	44	44.4	0.283	64
Alclad 2014	T6	Sheet	0.025 to 0.039	64.8	0.502	53	74.7	0.621	49	70.4	2.922	98	112.7	1.410	53	105.6	8.362	42	44.4	0.285	64
	T6	Sheet	0.040 to 0.249	67.3	0.531	52	77.6	0.658	48	73.0	3.068	94	117.2	1.496	52	109.5	8.779	41	46.2	0.302	63
	T651	Plate	0.250 to 0.499	64.8	0.502	53	74.7	0.621	49	70.4	2.922	98	112.7	1.410	53	105.6	8.362	42	46.2	0.302	63
3003	H12	Sheet & Plate	0.017 to 2.000	11.0	0.044	165	12.8	0.056	153	12.7	0.372	573	17.0	0.086	133	19.1	0.875	160	9.4	0.035	178
	H14	Sheet & Plate	0.009 to 1.000	15.7	0.075	138	18.4	0.096	127	18.1	0.594	416	24.5	0.148	111	27.1	1.398	127	13.8	0.062	147
	H16	Sheet	0.006 to 0.162	20.4	0.112	121	24.2	0.145	111	23.5	0.844	327	32.2	0.223	96	35.3	1.985	106	17.3	0.088	131
	H18	Sheet	0.006 to 0.128	22.8	0.133	114	27.1	0.172	105	26.3	0.977	295	36.1	0.264	91	39.4	2.300	99	20.0	0.109	122
	H12	Drawn Tube	All	12.2	0.052	157	14.2	0.065	145	14.1	0.425	523	18.9	0.100	126	21.1	0.999	150	9.4	0.035	178
	H14	Drawn Tube	All	18.0	0.093	129	21.3	0.120	119	20.8	0.716	366	28.3	0.184	103	31.2	1.684	115	13.8	0.062	147
	H16	Drawn Tube	All	21.6	0.123	118	25.7	0.158	108	24.9	0.910	310	34.1	0.243	94	37.4	2.141	102	17.3	0.088	131
	H18	Drawn Tube	All	24.0	0.144	112	28.6	0.187	102	27.7	1.046	281	38.1	0.287	89	41.5	2.462	95	20.0	0.109	122
Alclad 3003	H12	Sheet & Plate	0.017 to 2.000	9.9	0.038	174	11.5	0.047	162	11.4	0.321	635	15.2	0.072	140	17.1	0.756	172	8.6	0.031	187
	H14	Sheet & Plate	0.009 to 1.000	14.5	0.067	144	17.0	0.086	133	16.8	0.536	446	22.6	0.131	115	25.1	1.261	133	12.9	0.056	152
	H16	Sheet	0.006 to 0.162	19.2	0.103	125	22.7	0.132	115	22.2	0.779	345	30.2	0.203	99	33.3	1.833	111	16.4	0.081	135
	H18	Sheet	0.006 to 0.128	21.6	0.123	118	25.7	0.158	108	24.9	0.910	310	34.1	0.243	94	37.4	2.141	102	19.1	0.102	125
	H14	Drawn Tube	0.025 to 0.259	16.8	0.084	133	19.9	0.108	123	19.5	0.654	389	26.4	0.165	106	29.2	1.539	121	12.9	0.056	152
	H18	Drawn Tube	0.010 to 0.500	22.8	0.133	114	27.1	0.172	105	26.3	0.977	295	36.1	0.264	91	39.4	2.300	99	19.1	0.102	125
3004	H32	Sheet & Plate	0.017 to 2.000	20.4	0.112	121	24.2	0.145	111	23.5	0.844	327	32.2	0.223	96	35.3	1.985	106	17.3	0.088	131
	H34	Sheet & Plate	0.009 to 1.000	25.3	0.155	109	30.1	0.201	100	29.1	1.117	269	40.1	0.309	86	43.6	2.628	92	21.0	0.117	120
	H36	Sheet	0.006 to 0.162	29.0	0.190	102	34.6	0.248	93	33.2	1.335	238	46.1	0.382	81	49.8	3.142	85	23.7	0.141	112
	H38	Sheet	0.006 to 0.128	33.9	0.241	94	40.7	0.317	86	38.8	1.644	205	54.3	0.488	74	58.2	3.868	76	26.5	0.167	106
	H34	Drawn Tube	0.018 to 0.450	27.7	0.178	104	33.1	0.232	95	31.8	1.261	247	44.1	0.357	82	47.7	2.968	87	21.0	0.117	120
	H36	Drawn Tube	0.018 to 0.450	31.4	0.215	98	37.6	0.282	89	36.0	1.487	220	50.2	0.433	77	54.0	3.499	80	23.7	0.141	112
Alclad 3004	H32	Sheet	0.017 to 0.249	19.2	0.103	125	22.7	0.132	115	22.2	0.779	345	30.2	0.203	99	33.3	1.833	111	16.4	0.081	135
	H34	Sheet	0.009 to 0.249	24.0	0.144	112	28.6	0.187	102	27.7	1.046	282	38.1	0.287	89	41.5	2.462	95	20.0	0.109	122
	H36	Sheet	0.006 to 0.162	27.7	0.178	104	33.1	0.232	95	31.8	1.261	247	44.1	0.357	82	47.7	2.968	87	22.8	0.133	115
	H38	Sheet	0.006 to 0.128	32.7	0.228	96	39.2	0.299	87	37.4	1.565	213	52.2	0.460	76	56.1	3.682	78	25.6	0.158	108
	H131, H241, H341	Sheet	0.024 to 0.050	25.3	0.155	109	30.1	0.201	100	29.1	1.117	269	40.1	0.309	86	43.6	2.628	92	21.9	0.125	117
	H151, H261, H361	Sheet	0.024 to 0.050	32.7	0.228	96	39.2	0.299	87	37.4	1.565	213	52.2	0.460	76	56.1	3.682	78	25.6	0.158	108
3005	H25	Sheet	0.013 to 0.050	22.8	0.133	114	27.1	0.172	105	26.3	0.977	295	36.1	0.264	91	39.4	2.300	99	18.2	0.095	128
	H28	Sheet	0.006 to 0.080	29.0	0.190	102	34.6	0.248	93	33.2	1.335	238	46.1	0.382	81	49.8	3.142	85	22.8	0.133	115

Table 1-1
BUCKLING CONSTANTS (UNWELDED) (Continued)

Alloy	Temper	Product*	Thickness in.	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
3105	H25	Sheet	0.013 to 0.080	19.2	0.103	125	22.7	0.132	115	22.2	0.779	345	30.2	0.203	99	33.3	1.833	111	15.5	0.075	139
5005	H12	Sheet & Plate	0.017 to 2.000	14.5	0.067	144	17.0	0.086	133	16.8	0.536	446	22.6	0.131	115	25.1	1.261	133	11.1	0.045	164
	H14	Sheet & Plate	0.009 to 1.000	16.8	0.084	133	19.9	0.108	123	19.5	0.654	389	26.4	0.165	106	29.2	1.539	121	13.8	0.062	147
	H16	Sheet	0.006 to 0.162	20.4	0.112	121	24.2	0.145	111	23.5	0.844	327	32.2	0.223	96	35.3	1.985	106	16.4	0.081	135
	H32	Sheet & Plate	0.017 to 2.000	12.2	0.052	157	14.2	0.065	145	14.1	0.425	523	18.9	0.100	126	21.1	0.999	150	9.4	0.035	178
	H34	Sheet & Plate	0.009 to 1.000	15.7	0.075	138	18.4	0.096	127	18.1	0.594	416	24.5	0.148	111	27.1	1.398	127	12.0	0.051	158
	H36	Sheet	0.006 to 0.162	18.0	0.093	129	21.3	0.120	119	20.8	0.716	366	28.3	0.184	103	31.2	1.684	115	14.6	0.068	143
5050	H32	Sheet	0.017 to 0.249	15.7	0.075	138	18.4	0.096	127	18.1	0.594	416	24.5	0.148	111	27.1	1.398	127	12.9	0.056	152
	H34	Sheet	0.009 to 0.249	20.4	0.112	121	24.2	0.145	111	23.5	0.844	327	32.2	0.223	96	35.3	1.985	106	16.4	0.081	135
	H32	Rod & Bar, Drawn Tube	All	16.8	0.084	133	19.9	0.108	123	19.5	0.654	389	26.4	0.165	106	29.2	1.539	121	12.9	0.056	152
	H34	Rod & Bar, Drawn Tube	All	21.6	0.123	118	25.7	0.158	108	24.9	0.910	310	34.1	0.243	94	37.4	2.141	102	16.4	0.081	135
5052	O	Sheet & Plate	0.006 to 3.000	10.4	0.041	170	12.1	0.051	158	12.1	0.345	608	16.1	0.078	137	18.1	0.812	167	7.3	0.024	203
	H32	Sheet & Plate, Rod & Bar, Drawn Tube	All	24.0	0.143	112	28.6	0.186	103	27.7	1.043	284	38.1	0.285	89	41.5	2.454	96	19.1	0.101	126
	H34		All	27.7	0.177	104	33.1	0.231	96	31.8	1.257	250	44.1	0.355	83	47.7	2.958	88	21.9	0.124	118
	H36	Sheet	0.006 to 0.162	30.2	0.201	100	36.1	0.263	91	34.6	1.406	231	48.1	0.405	79	51.9	3.308	83	24.7	0.148	111
5083	O	Extrusions	up thru 5.000	18.0	0.092	131	21.3	0.118	120	20.8	0.709	376	28.3	0.181	104	31.2	1.668	118	12.9	0.056	155
	H111	Extrusions	up thru 0.500	24.0	0.142	113	28.6	0.184	104	27.7	1.036	289	38.1	0.282	90	41.5	2.438	97	20.0	0.108	124
	H111	Extrusions	0.501 to 5.000	24.0	0.142	113	28.6	0.184	104	27.7	1.036	289	38.1	0.282	90	41.5	2.438	97	20.0	0.108	124
	O	Sheet & Plate	0.051 to 1.500	20.4	0.111	123	24.2	0.143	113	23.5	0.835	336	32.2	0.219	98	35.3	1.966	108	14.6	0.067	145
	H116, H32, H321	Sheet & Plate	0.188 to 1.500	30.2	0.199	101	36.1	0.261	92	34.6	1.397	235	48.1	0.401	80	51.9	3.287	84	26.5	0.164	108
	H116, H32, H321	Plate	1.501 to 3.000	27.7	0.175	105	33.1	0.229	96	31.8	1.249	254	44.1	0.352	84	47.7	2.939	89	24.7	0.147	112
5086	O	Extrusions	up thru 5.000	15.7	0.074	140	18.4	0.095	129	18.1	0.588	427	24.5	0.146	112	27.1	1.385	129	11.1	0.045	166
	H111	Extrusions	up thru 5.000	20.4	0.111	123	24.2	0.143	113	23.5	0.835	336	32.2	0.219	98	35.3	1.966	108	17.3	0.087	133
	O	Sheet & Plate	0.020 to 2.000	15.7	0.074	140	18.4	0.095	129	18.1	0.588	421	24.5	0.146	112	27.1	1.385	129	11.1	0.045	166
	H112	Plate	0.025 to 0.499	19.2	0.101	127	22.7	0.130	116	22.2	0.771	355	30.2	0.200	101	33.3	1.815	113	14.6	0.067	145
	H112	Plate	0.500 to 1.000	18.0	0.092	131	21.3	0.118	120	20.8	0.709	375	28.3	0.181	104	31.2	1.668	118	12.9	0.056	155
	H112	Plate	1.001 to 2.000	16.8	0.083	135	19.9	0.106	125	19.5	0.648	400	26.4	0.163	108	29.2	1.524	123	11.1	0.045	166
	H112	Plate	2.001 to 3.000	16.8	0.083	135	19.9	0.106	125	19.5	0.648	400	26.4	0.163	108	29.2	1.524	123	11.1	0.045	166
	H116	Sheet & Plate	All	30.2	0.199	101	36.1	0.261	92	34.6	1.397	235	48.1	0.401	80	51.9	3.287	84	23.7	0.139	114
	H32	Sheet & Plate, Drawn Tube	All	30.2	0.199	101	36.1	0.261	92	34.6	1.397	235	48.1	0.401	80	51.9	3.287	84	23.7	0.139	114
	H34	Sheet & Plate, Drawn Tube	All	37.7	0.278	90	45.4	0.367	82	43.1	1.869	192	60.5	0.565	71	64.6	4.397	73	29.4	0.191	102
5154	H38	Sheet	0.006 to 0.128	39.0	0.294	88	46.9	0.388	81	44.5	1.957	184	62.6	0.598	70	66.7	4.605	71	30.3	0.202	100

Table 1-1
BUCKLING CONSTANTS (UNWELDED) (Continued)

Alloy	Temper	Product*	Thickness in.	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
5454	O	Extrusions	up thru 5.000	13.3	0.058	152	15.6	0.074	140	15.4	0.475	495	20.7	0.113	122	23.1	1.117	144	9.4	0.035	181
	H111	Extrusions	up thru 0.500	18.0	0.092	131	21.3	0.118	120	20.8	0.709	376	28.3	0.181	104	31.2	1.668	118	15.5	0.073	141
	H111	Extrusions	0.501 to 5.000	18.0	0.092	131	21.3	0.118	120	20.8	0.709	376	28.3	0.181	104	31.2	1.668	118	15.5	0.073	141
	H112	Extrusions	up thru 5.000	14.5	0.066	146	17.0	0.084	135	16.8	0.531	458	22.6	0.129	117	25.1	1.249	136	9.4	0.035	181
	O	Sheet & Plate	0.020 to 3.000	13.3	0.058	152	15.6	0.074	140	15.4	0.475	495	20.7	0.113	122	23.1	1.117	144	9.4	0.035	181
	H32	Sheet & Plate	0.020 to 2.000	27.7	0.175	105	33.1	0.229	96	31.8	1.249	254	44.1	0.352	84	47.7	2.939	89	21.9	0.123	119
	H34	Sheet & Plate	0.020 to 1.000	31.4	0.212	99	37.6	0.277	90	36.0	1.473	227	50.2	0.427	78	54.0	3.465	82	24.7	0.147	112
5456	O	Sheet & Plate	0.051 to 1.500	21.6	0.121	119	25.7	0.156	110	24.9	0.901	499	34.1	0.240	95	37.4	2.120	104	15.5	0.073	141
	H116	Sheet & Plate	0.188 to 1.250	31.4	0.212	99	37.6	0.277	90	36.0	1.473	227	50.2	0.427	78	54.0	3.465	82	28.4	0.182	104
	H32, H321	Sheet & Plate	0.188 to 0.499	31.4	0.212	99	37.6	0.277	90	36.0	1.473	227	50.2	0.427	78	54.0	3.465	82	28.4	0.182	104
	H116	Plate	1.251 to 1.500	29.0	0.187	103	34.6	0.245	94	33.2	1.322	244	46.1	0.376	82	49.8	3.112	86	26.5	0.164	108
	H32, H321	Plate	0.501 to 1.500	29.0	0.187	103	34.6	0.245	94	33.2	1.322	244	46.1	0.376	82	49.8	3.112	86	26.5	0.164	108
	H116, H32, H321	Plate	1.501 to 3.000	29.0	0.187	103	34.6	0.245	94	33.2	1.322	244	46.1	0.376	82	49.8	3.112	86	24.7	0.147	112
6005	T5	Extrusions	up thru 1.000	39.4	0.246	66	45.0	0.300	61	43.2	1.558	141	66.8	0.666	67	64.8	4.458	55	27.2	0.141	79
6005A	T61	Extrusions	up thru 1.000	39.4	0.246	66	45.0	0.300	61	43.2	1.558	141	66.8	0.666	67	64.8	4.458	55	27.2	0.141	79
6061	T6, T651	Sheet & Plate	0.010 to 4.000	39.4	0.246	66	45.0	0.300	61	43.2	1.558	141	66.8	0.666	67	64.8	4.458	55	27.2	0.141	79
	T6, T6510, T6511	Extrusions	All	39.4	0.246	66	45.0	0.300	61	43.2	1.558	141	66.8	0.666	67	64.8	4.458	55	27.2	0.141	79
	T6, T651	Rod & Bar	up thru 8.000	39.4	0.246	66	45.0	0.300	61	43.2	1.558	141	66.8	0.666	67	64.8	4.458	55	27.2	0.141	79
	T6	Drawn Tube	0.025 to 0.500	39.4	0.246	66	45.0	0.300	61	43.2	1.558	141	66.8	0.666	67	64.8	4.458	55	27.2	0.141	79
	T6	Pipe	All	39.4	0.246	66	45.0	0.300	61	43.2	1.558	141	66.8	0.666	67	64.8	4.458	55	27.2	0.141	79
6063	T5	Extrusions	up thru 0.500	17.3	0.072	99	19.5	0.086	93	19.2	0.529	275	28.3	0.184	103	28.8	1.513	95	11.8	0.040	120
	T5	Extrusions	0.500 to 1.000	16.2	0.065	102	18.2	0.077	97	18.0	0.484	290	26.4	0.165	106	26.9	1.384	100	11.0	0.036	124
	T52	Extrusions	up thru 1.000	17.3	0.072	99	19.5	0.086	93	19.2	0.529	275	28.3	0.184	103	28.8	1.513	95	11.8	0.040	120
	T6	Extrusions & Pipe	All	27.6	0.145	78	31.4	0.175	74	30.5	0.978	189	46.1	0.382	81	45.7	2.800	70	19.0	0.082	95
6066	T6, T6510, T6511	Extrusions	All	51.4	0.366	57	59.0	0.451	54	56.1	2.206	112	88.3	1.011	58	84.1	6.313	47	35.7	0.212	69
6070	T6, T62	Extrusions	up thru 2.999	51.4	0.366	57	59.0	0.451	54	56.1	2.206	112	88.3	1.011	58	84.1	6.313	47	35.7	0.212	69
6082	T6, T6511	Extrusions	0.200 thru 6.000	42.9	0.280	63	49.2	0.343	59	47.0	1.745	131	73.2	0.763	64	70.6	4.995	52	29.8	0.162	76
6105	T5	Extrusions	up thru 0.500	39.4	0.246	66	45.0	0.300	61	43.2	1.558	141	66.8	0.666	67	64.8	4.458	55	27.2	0.141	79
6351	T5	Extrusions	up thru 1.000	39.4	0.246	66	45.0	0.300	61	43.2	1.558	141	66.8	0.666	67	64.8	4.458	55	27.2	0.141	79
6351	T6	Extrusions	up thru 0.750	41.7	0.268	64	47.8	0.329	60	45.8	1.682	134	71.1	0.730	65	68.6	4.814	53	28.9	0.155	77
6463	T6	Extrusions	up thru 0.500	27.6	0.145	78	31.4	0.175	74	30.5	0.978	189	46.1	0.382	81	45.7	2.800	70	19.0	0.082	95
7005	T53	Extrusions	up thru 0.750	48.9	0.334	60	56.2	0.411	56	53.5	2.045	121	84.0	0.920	61	80.2	5.852	49	34.9	0.201	71

Table 1-2
BUCKLING CONSTANTS (WELDED)

Alloy	Temper	Product	Thickness in.	B_c ksi	D_c ksi	C_c	B_p ksi	D_p ksi	C_p	B_t ksi	D_t ksi	C_t	B_{br} ksi	D_{br} ksi	C_{br}	B_{tb} ksi	D_{tb} ksi	C_{tb}	B_s ksi	D_s ksi	C_s
1100	All	Sheet & Plate, Drawn Tube		3.7	0.009	284	4.2	0.010	267	4.3	0.087	1375	5.5	0.016	232	6.4	0.204	332	2.5	0.005	344
1100	All	Rod & Bar		3.2	0.007	308	3.6	0.008	290	3.6	0.070	1540	4.7	0.012	252	5.5	0.165	369	2.2	0.004	373
3003	All	Sheet & Plate, Drawn Tube		5.4	0.015	236	6.1	0.018	221	6.2	0.142	1066	8.1	0.028	192	9.3	0.335	259	3.7	0.009	285
Alclad 3003	All	Sheet & Plate, Drawn Tube		4.8	0.013	250	5.5	0.016	234	5.6	0.123	1150	7.2	0.024	203	8.3	0.289	279	3.3	0.007	301
3004	All	Sheet & Plate		9.3	0.034	180	10.8	0.043	167	10.8	0.297	672	14.3	0.066	145	16.1	0.698	179	6.5	0.020	214
3004	All	Drawn Tube		9.3	0.034	180	10.8	0.043	167	10.8	0.297	672	14.3	0.066	145	16.1	0.698	179	6.5	0.020	214
Alclad 3004	All	Sheet		8.7	0.031	185	10.1	0.039	172	10.1	0.273	715	13.4	0.060	150	15.1	0.642	187	6.1	0.018	221
3005	All	Sheet		7.0	0.023	206	8.1	0.028	192	8.1	0.204	875	10.7	0.043	167	12.2	0.481	216	4.9	0.013	247
5005	All	Sheet & Plate		5.4	0.015	236	6.1	0.018	221	6.2	0.142	1066	8.1	0.028	192	9.3	0.335	259	3.7	0.009	285
5050	All	Sheet & Plate, Drawn Tube, Rod & Bar		6.5	0.020	215	7.4	0.025	201	7.5	0.183	932	9.8	0.038	174	11.2	0.431	228	4.5	0.012	258
5052	All	Sheet & Plate, Rod & Bar		10.4	0.041	170	12.1	0.051	158	12.1	0.345	608	16.1	0.078	137	18.1	0.812	167	7.3	0.024	203
5052	All	Drawn Tube		11.0	0.044	166	12.8	0.056	153	12.7	0.371	580	17.0	0.085	133	19.1	0.872	161	7.8	0.026	197
5083	All	Extrusions		18.0	0.092	131	21.3	0.118	120	20.8	0.709	551	28.3	0.181	104	31.2	1.668	118	12.9	0.056	155
5083	All	Sheet & Plate	0.188 to 1.500	20.4	0.111	123	24.2	0.143	113	23.5	0.835	336	32.2	0.219	98	35.3	1.966	108	14.6	0.067	145
5083	All	Plate	1.501 to 3.000	19.2	0.101	127	22.7	0.130	116	22.2	0.771	532	30.2	0.200	101	33.3	1.815	113	13.8	0.061	150
5086	All	Sheet & Plate, Extrusions, Drawn Tube		15.7	0.074	140	18.4	0.095	129	18.1	0.588	427	24.5	0.146	112	27.1	1.385	129	11.1	0.045	166
5154	All	Sheet		12.2	0.051	158	14.2	0.065	147	14.1	0.422	680	18.9	0.099	127	21.1	0.993	152	8.6	0.030	188
5454	All	Sheet & Plate, Extrusions		13.3	0.058	152	15.6	0.074	140	15.4	0.475	495	20.7	0.113	122	23.1	1.117	144	9.4	0.035	181
5456	All	Sheet & Plate	0.188-1.500	21.6	0.121	119	25.7	0.156	110	24.9	0.901	499	34.1	0.240	95	37.4	2.120	104	15.5	0.073	141
5456	All	Plate	1.501-3.000	19.2	0.101	127	22.7	0.130	116	22.2	0.771	532	30.2	0.200	101	33.3	1.815	113	14.6	0.067	145
6005	T5	Extrusions	up thru 1.000	14.5	0.067	144	17.0	0.086	133	16.8	0.536	446	22.6	0.131	115	25.1	1.261	133	10.3	0.040	171
6005A	T61	Extrusions	up thru 1.000	14.5	0.067	144	17.0	0.086	133	16.8	0.536	446	22.6	0.131	115	25.1	1.261	133	10.3	0.040	171
6061	T6, T651, T6510, T6511[1]	All		16.8	0.084	133	19.9	0.108	123	19.5	0.654	390	26.4	0.165	106	29.2	1.539	121	12.0	0.051	158
6061	T6, T651, T6510, T6511[2]	All	over 0.375	12.2	0.052	157	14.2	0.065	145	14.1	0.425	524	18.9	0.100	126	21.1	0.999	150	8.6	0.031	187
6063	T5, T52, T6	All		8.7	0.031	185	10.1	0.039	172	10.1	0.273	715	13.4	0.060	150	15.1	0.642	187	6.1	0.018	221
6082	T6, T6511	Extrusions	0.200 to 6.000	18.0	0.093	129	21.3	0.120	119	20.8	0.716	366	28.3	0.184	103	31.2	1.684	115	12.9	0.056	152
6105	T5	Extrusions	up thru 0.500	14.5	0.067	144	17.0	0.086	133	16.8	0.536	446	22.6	0.131	115	25.1	1.261	133	10.3	0.040	171
6351	T5, T6[1]	Extrusions		16.8	0.084	133	19.9	0.108	123	19.5	0.654	390	26.4	0.165	106	29.2	1.539	121	12.0	0.051	158
6351	T5, T6[2]	Extrusions	over 0.375	12.2	0.052	157	14.2	0.065	145	14.1	0.425	524	18.9	0.100	126	21.1	0.999	150	8.6	0.031	187
6463	T6	Extrusions	up thru 0.500	8.7	0.031	185	10.1	0.039	172	10.1	0.273	715	13.4	0.060	150	15.1	0.642	187	6.1	0.018	221
7005	T53	Extrusions	up thru 0.750	27.7	0.174	106	33.1	0.228	97	31.8	1.245	257	44.1	0.350	84	47.7	2.929	89	20.0	0.107	125

1. When welded with 5183, 5356, or 5556 alloy filler regardless of thickness, and when welded with 4043, 5554, or 5654 alloy filler for thickness ≤ 0.375 in.
2. When welded with 4043, 5554, or 5654 alloy filler for thickness > 0.375 in.

Allowable Stresses for Building-Type Structures

Tables 2-1 through 2-24 and 2-1W through 2-24W

1. These tables provide allowable stresses F/Ω for building-type structures determined in accordance with the Specification for Aluminum Structures.
2. Buckling constants used to calculate values in these tables are calculated from mechanical properties given in Part I Tables A.3.4 and A.3.5 rather than the rounded buckling constants given in Part VI Tables 1-1 and 1-2.
3. For tubes with circumferential welds, equations apply for $R_b/t < 20$.

Table 2-1
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

1100 – H14 **Sheet, Plate, Drawn Tube**

$F_{ty} = 14\ \text{k/in}^2$ $E = 10{,}100\ \text{k/in}^2$
$F_{cy} = 13\ \text{k/in}^2$ $k_t = 1$
$F_{tu} = 16\ \text{k/in}^2$

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**	
Axial Tension			
axial tension stress on net effective area	D.2b	8.2	
axial tension stress on gross area	D.2a	8.5	
Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	8.2	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	11.0	10.2 see also F.4.2
round tubes	F.6.1	9.9	9.2 see also F.6.2
rods	F.7	11.0	10.2
Bearing			
bolts or rivets on holes	J.3.7a, J.4.7	16.4	
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	10.9	

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$7.5 - 0.035\ S$	144	$51{,}352\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b{}^{1/2})$			$8.8 - 0.034\ S$	172	$86{,}996\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$8.8 - 0.065\ S^{1/2}$	8072	$23{,}599\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$13.7 - 0.182\ S$	50	$11{,}420\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$15.2 - 0.764\ S^{1/2}$	133	$10.2 - 0.325\ S^{1/2}$	446	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	7.9	9.4	$10.3 - 0.259\ S$	27	$2{,}417\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	7.9	9.4	$10.3 - 0.259\ S$	19.9	$103\ /S$
flat elements supported on both edges	B.5.4.2	b/t	7.9	29.4	$10.3 - 0.083\ S$	62	$320\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	7.9	22.1	$8.8 - 0.041\ S$	144	$60{,}414\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	7.9	49.0	$10.2 - 0.325\ S^{1/2}$	446	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	7.9	47.0	$10.3 - 0.052\ S$	99	$513\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	10.2	66.9	$13.7 - 0.052\ S$	133	$909\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	10.2	12.4	$13.7 - 0.278\ S$	33	$4{,}932\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	10.2	150.0	$13.7 - 0.023\ S$	298	$2{,}037\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	10.2	43.5	$13.7 - 0.079\ S$	86	$591\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	5.1	48.5	$6.8 - 0.034\ S$	131	$38{,}665\ /S^2$

Table 2-2
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

3003 – H14	**Sheet, Plate, Drawn Tube**
F_{ty} = 17 k/in^2	E = 10,100 k/in^2
F_{cy} = 14 k/in^2	k_t = 1
F_{tu} = 20 k/in^2	

Allowable Stresses F/Ω (k/in^2)	Section	F/Ω	
Axial Tension			
axial tension stress on net effective area	D.2b	10.3	
axial tension stress on gross area	D.2a	10.3	
		Tension	**Compression**
Flexure			
elements in uniform stress	F.8.1.1	10.3	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	13.4	11.0 see also F.4.2
round tubes	F.6.1	12.1	9.9 see also F.6.2
rods	F.7	13.4	11.0
Bearing			
bolts or rivets on holes	J.3.7a, J.4.7	20.5	
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	13.6	

		Slenderness S	F/Ω **for** $S \le S_1$	S_1	F/Ω **for** $S_1 < S < S_2$	S_2	F/Ω **for** $S \ge S_2$
Axial Compression							
all shapes member buckling	E.3	kL/r			8.1 – 0.039 S	138	51,352 /S^2
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			9.5 – 0.038 S	166	86,996 /S^2
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			9.5 – 0.073 $S^{1/2}$	7466	23,599 /S
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			14.8 – 0.206 S	48	11,420 /S^2
round tubes local buckling	F.6.2	R_b/t	16.5 – 0.847 $S^{1/2}$	127	11.0 – 0.360 $S^{1/2}$	416	3,776 /[$S(1+S^{1/2}/35)^2$]
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	8.5	9.2	11.2 – 0.292 S	25	2,417 /S^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	8.5	9.2	11.2 – 0.292 S	19.1	107 /S
flat elements supported on both edges	B.5.4.2	b/t	8.5	28.7	11.2 – 0.094 S	60	333 /S
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	8.5	21.9	9.5 – 0.046 S	138	60,414 /S^2
curved elements supported on both edges	B.5.4.5	R_b/t	8.5	47.6	11.0 – 0.360 $S^{1/2}$	416	3,776 /[$S(1+S^{1/2}/35)^2$]
flat elements—alternate method	B.5.4.6	λ_{eq}	8.5	46.0	11.2 – 0.058 S	96	534 /S
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	11.0	65.5	14.8 – 0.058 S	128	946 /S
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	11.0	12.2	14.8 – 0.313 S	32	4,932 /S^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	11.0	146.8	14.8 – 0.026 S	286	2,120 /S
flat elements—alternate method	B.5.5.4	λ_{eq}	11.0	42.6	14.8 – 0.089 S	83	615 /S
Elements—Shear							
flat elements supported on both edges	G.2	b/t	6.2	45.8	8.3 – 0.047 S	118	38,665 /S^2

Table 2-3
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

3003 – H16 **Sheet**

F_{ty} = 21 k/in² E = 10,100 k/in²
F_{cy} = 18 k/in² k_t = 1
F_{tu} = 24 k/in²

Allowable Stresses F/Ω (k/in²)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	12.3
axial tension stress on gross area	D.2a	12.7

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	12.3	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	16.5	14.2 see also F.4.2
round tubes	F.6.1	14.9	12.8 see also F.6.2
rods	F.7	16.5	14.2

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	24.6
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	16.4

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			10.5 – 0.058 S	121	51,352 /S^2
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			12.4 – 0.057 S	145	86,996 /S^2
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			12.4 – 0.109 $S^{1/2}$	5726	23,599 /S
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			19.5 – 0.310 S	42	11,420 /S^2
round tubes local buckling	F.6.2	R_b/t	21.4 – 1.203 $S^{1/2}$	106	14.3 – 0.511 $S^{1/2}$	327	3,776 /[$S(1+S^{1/2}/35)^2$]
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	10.9	8.5	14.7 – 0.440 S	22	2,417 /S^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	10.9	8.5	14.7 – 0.440 S	16.7	122 /S
flat elements supported on both edges	B.5.4.2	b/t	10.9	26.7	14.7 – 0.141 S	52	382 /S
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	10.9	21.5	12.4 – 0.068 S	121	60,414 /S^2
curved elements supported on both edges	B.5.4.5	R_b/t	10.9	43.2	14.3 – 0.511 $S^{1/2}$	327	3,776 /[$S(1+S^{1/2}/35)^2$]
flat elements—alternate method	B.5.4.6	λ_{eq}	10.9	42.7	14.7 – 0.088 S	83	611 /S
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	14.2	60.7	19.5 – 0.088 S	111	1,085 /S
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	14.2	11.3	19.5 – 0.472 S	28	4,932 /S^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	14.2	136.2	19.5 – 0.039 S	249	2,431 /S
flat elements—alternate method	B.5.5.4	λ_{eq}	14.2	39.5	19.5 – 0.135 S	72	705 /S
Elements—Shear							
flat elements supported on both edges	G.2	b/t	7.6	43.0	10.5 – 0.067 S	105	38,665 /S^2

Table 2-4
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

Alclad 3004 – H34 **Sheet**

$F_{ty} = 24$ k/in^2 $E = 10{,}100$ k/in^2
$F_{cy} = 21$ k/in^2 $k_t = 1$
$F_{tu} = 31$ k/in^2

Allowable Stresses F/Ω (k/in^2)	Section	F/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	15.9
axial tension stress on gross area	D.2a	14.5

Flexure		Tension	Compression	
elements in uniform stress	F.8.1.1	14.5	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	18.9	16.5	see also F.4.2
round tubes	F.6.1	17.0	14.9	see also F.6.2
rods	F.7	18.9	16.5	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	31.8
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	21.1

		Slenderness S	F/Ω for $S \leq S_1$	S_1	F/Ω for $S_1 < S < S_2$	S_2	F/Ω for $S \geq S_2$
Axial Compression							
all shapes member buckling	E.3	kL/r			$12.4 - 0.074\ S$	112	$51{,}352\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$14.6 - 0.073\ S$	134	$86{,}996\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$14.6 - 0.139\ S^{1/2}$	4862	$23{,}599\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$23.1 - 0.399\ S$	39	$11{,}420\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$25.2 - 1.492\ S^{1/2}$	95	$16.8 - 0.634\ S^{1/2}$	282	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	12.7	8.2	$17.3 - 0.565\ S$	20	$2{,}417\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	12.7	8.2	$17.3 - 0.565\ S$	15.3	$133\ /S$
flat elements supported on both edges	B.5.4.2	b/t	12.7	25.5	$17.3 - 0.181\ S$	48	$415\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	12.7	21.2	$14.6 - 0.087\ S$	112	$60{,}414\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	12.7	40.6	$16.8 - 0.634\ S^{1/2}$	282	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	12.7	40.8	$17.3 - 0.113\ S$	77	$665\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	16.5	57.9	$23.1 - 0.113\ S$	102	$1{,}180\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	16.5	10.8	$23.1 - 0.608\ S$	25	$4{,}932\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	16.5	129.9	$23.1 - 0.050\ S$	229	$2{,}644\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	16.5	37.7	$23.1 - 0.174\ S$	66	$767\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	8.7	41.3	$12.1 - 0.083\ S$	98	$38{,}665\ /S^2$

Table 2-5
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5005 – H14 **Sheet and Plate**

F_{ty} = 17 k/in^2
F_{cy} = 15 k/in^2
F_{tu} = 21 k/in^2
E = 10,100 k/in^2
k_t = 1

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	10.8
axial tension stress on gross area	D.2a	10.3

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	10.3	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	13.4	11.8 see also F.4.2
round tubes	F.6.1	12.1	10.6 see also F.6.2
rods	F.7	13.4	11.8

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	21.5
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	14.3

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$8.7 - 0.043\,S$	133	$51{,}352\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b{}^{1/2})$			$10.2 - 0.043\,S$	160	$86{,}996\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$10.2 - 0.082\,S^{1/2}$	6943	$23{,}599\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$16.0 - 0.230\,S$	46	$11{,}420\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$17.7 - 0.933\,S^{1/2}$	121	$11.8 - 0.396\,S^{1/2}$	390	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.1	9.0	$12.0 - 0.327\,S$	25	$2{,}417\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.1	9.0	$12.0 - 0.327\,S$	18.4	$111\,/S$
flat elements supported on both edges	B.5.4.2	b/t	9.1	28.2	$12.0 - 0.105\,S$	58	$346\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.1	21.8	$10.2 - 0.051\,S$	133	$60{,}414\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	9.1	46.4	$11.8 - 0.396\,S^{1/2}$	390	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	9.1	45.1	$12.0 - 0.065\,S$	92	$554\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	11.8	64.2	$16.0 - 0.065\,S$	123	$982\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	11.8	11.9	$16.0 - 0.350\,S$	30	$4{,}932\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	11.8	143.8	$16.0 - 0.029\,S$	275	$2{,}201\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	11.8	41.7	$16.0 - 0.100\,S$	80	$638\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	6.2	45.8	$8.3 - 0.047\,S$	118	$38{,}665\,/S^2$

Table 2-6
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5005 – H32 **Sheet and Plate**

F_{ty} = 12 k/in^2 E = 10,100 k/in^2
F_{cy} = 11 k/in^2 k_t = 1
F_{tu} = 17 k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**		
Axial Tension				
axial tension stress on net effective area	D.2b	8.7		
axial tension stress on gross area	D.2a	7.3		
Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	7.3	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	9.5	8.7	see also F.4.2
round tubes	F.6.1	8.5	7.8	see also F.6.2
rods	F.7	9.5	8.7	
Bearing				
bolts or rivets on holes	J.3.7a, J.4.7	17.4		
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	11.6		

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			6.3 – 0.027 S	157	51,352 /S^2
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			7.4 – 0.026 S	188	86,996 /S^2
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			7.4 – 0.050 $S^{1/2}$	9618	23,599 /S
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			11.4 – 0.139 S	55	11,420 /S^2
round tubes local buckling	F.6.2	R_b/t	12.8 – 0.606 $S^{1/2}$	150	8.5 – 0.257 $S^{1/2}$	524	3,776 /[$S(1+S^{1/2}/35)^2$]
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	6.7	9.8	8.6 – 0.198 S	29	2,417 /S^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	6.7	9.8	8.6 – 0.198 S	21.8	94 /S
flat elements supported on both edges	B.5.4.2	b/t	6.7	30.8	8.6 – 0.063 S	68	293 /S
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	6.7	22.3	7.4 – 0.031 S	157	60,414 /S^2
curved elements supported on both edges	B.5.4.5	R_b/t	6.7	52.2	8.5 – 0.257 $S^{1/2}$	524	3,776 /[$S(1+S^{1/2}/35)^2$]
flat elements—alternate method	B.5.4.6	λ_{eq}	6.7	49.2	8.6 – 0.040 S	109	468 /S
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	8.7	70.3	11.4 – 0.039 S	145	830 /S
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	8.7	13.0	11.4 – 0.212 S	36	4,932 /S^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	8.7	157.5	11.4 – 0.018 S	326	1,861 /S
flat elements—alternate method	B.5.5.4	λ_{eq}	8.7	45.7	11.4 – 0.060 S	94	540 /S
Elements—Shear							
flat elements supported on both edges	G.2	b/t	4.4	50.7	5.7 – 0.027 S	142	38,665 /S^2

Table 2-7
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5005 – H34 **Sheet and Plate**

$F_{ty} = 15$ k/in^2 $E = 10{,}100$ k/in^2
$F_{cy} = 14$ k/in^2 $k_t = 1$
$F_{tu} = 20$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	10.3
axial tension stress on gross area	D.2a	9.1

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	9.1	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	11.8	11.0	see also F.4.2
round tubes	F.6.1	10.6	9.9	see also F.6.2
rods	F.7	11.8	11.0	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	20.5
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	13.6

Axial Compression		**Slenderness S**	**F/Ω for $S \leq S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \geq S_2$**
all shapes member buckling	E.3	kL/r			$8.1 - 0.039\ S$	138	$51{,}352\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$9.5 - 0.038\ S$	166	$86{,}996\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$9.5 - 0.073\ S^{1/2}$	7466	$23{,}599\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$14.8 - 0.206\ S$	48	$11{,}420\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$16.5 - 0.847\ S^{1/2}$	127	$11.0 - 0.360\ S^{1/2}$	416	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	8.5	9.2	$11.2 - 0.292\ S$	25	$2{,}417\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	8.5	9.2	$11.2 - 0.292\ S$	19.1	$107\ /S$
flat elements supported on both edges	B.5.4.2	b/t	8.5	28.7	$11.2 - 0.094\ S$	60	$333\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	8.5	21.9	$9.5 - 0.046\ S$	138	$60{,}414\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	8.5	47.6	$11.0 - 0.360\ S^{1/2}$	416	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	8.5	46.0	$11.2 - 0.058\ S$	96	$534\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	11.0	65.5	$14.8 - 0.058\ S$	128	$946\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	11.0	12.2	$14.8 - 0.313\ S$	32	$4{,}932\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	11.0	146.8	$14.8 - 0.026\ S$	286	$2{,}120\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	11.0	42.6	$14.8 - 0.089\ S$	83	$615\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	5.5	47.5	$7.3 - 0.038\ S$	126	$38{,}665\ /S^2$

Table 2-8
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5050 – H34 **Sheet**

$F_{ty} = 20$ k/in^2 $E = 10{,}100$ k/in^2
$F_{cy} = 18$ k/in^2 $k_t = 1$
$F_{tu} = 25$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	12.8
axial tension stress on gross area	D.2a	12.1

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	12.1	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	15.8	14.2	see also F.4.2
round tubes	F.6.1	14.2	12.8	see also F.6.2
rods	F.7	15.8	14.2	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	25.6
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	17.1

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$10.5 - 0.058\ S$	121	$51{,}352\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$12.4 - 0.057\ S$	145	$86{,}996\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$12.4 - 0.109\ S^{1/2}$	5726	$23{,}599\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$19.5 - 0.310\ S$	42	$11{,}420\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$21.4 - 1.203\ S^{1/2}$	106	$14.3 - 0.511\ S^{1/2}$	327	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	10.9	8.5	$14.7 - 0.440\ S$	22	$2{,}417\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	10.9	8.5	$14.7 - 0.440\ S$	16.7	$122\ /S$
flat elements supported on both edges	B.5.4.2	b/t	10.9	26.7	$14.7 - 0.141\ S$	52	$382\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	10.9	21.5	$12.4 - 0.068\ S$	121	$60{,}414\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	10.9	43.2	$14.3 - 0.511\ S^{1/2}$	327	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	10.9	42.7	$14.7 - 0.088\ S$	83	$611\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	14.2	60.7	$19.5 - 0.088\ S$	111	$1{,}085\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	14.2	11.3	$19.5 - 0.472\ S$	28	$4{,}932\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	14.2	136.2	$19.5 - 0.039\ S$	249	$2{,}431\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	14.2	39.5	$19.5 - 0.135\ S$	72	$705\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	7.3	43.6	$10.0 - 0.061\ S$	108	$38{,}665\ /S^2$

Table 2-9
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5052 – H32 **Sheet, Plate, Drawn Tube**

$F_{ty} = 23$ k/in^2 $E = 10{,}200$ k/in^2
$F_{cy} = 21$ k/in^2 $k_t = 1$
$F_{tu} = 31$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**	
Axial Tension			
axial tension stress on net effective area	D.2b	15.9	
axial tension stress on gross area	D.2a	13.9	
Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	13.9	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	18.1	16.5 see also F.4.2
round tubes	F.6.1	16.3	14.9 see also F.6.2
rods	F.7	18.1	16.5
Bearing			
bolts or rivets on holes	J.3.7a, J.4.7	31.8	
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	21.1	

		Slenderness S	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
Axial Compression							
all shapes member buckling	E.3	kL/r			$12.4 - 0.074\,S$	112	$51{,}860/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$14.6 - 0.072\,S$	135	$87{,}857/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$14.6 - 0.139\,S^{1/2}$	4910	$23{,}833/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$23.1 - 0.397\,S$	39	$11{,}533/S^2$
round tubes local buckling	F.6.2	R_b/t	$25.2 - 1.487\,S^{1/2}$	96	$16.8 - 0.632\,S^{1/2}$	285	$3{,}813/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	12.7	8.2	$17.3 - 0.563\,S$	21	$2{,}440/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	12.7	8.2	$17.3 - 0.563\,S$	15.4	$134/S$
flat elements supported on both edges	B.5.4.2	b/t	12.7	25.6	$17.3 - 0.180\,S$	48	$417/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	12.7	21.3	$14.6 - 0.087\,S$	112	$61{,}012/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	12.7	40.9	$16.8 - 0.632\,S^{1/2}$	285	$3{,}813/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	12.7	41.0	$17.3 - 0.113\,S$	77	$668/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	16.5	58.2	$23.1 - 0.112\,S$	103	$1{,}186/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	16.5	10.8	$23.1 - 0.605\,S$	25	$4{,}981/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	16.5	130.5	$23.1 - 0.050\,S$	230	$2{,}657/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	16.5	37.9	$23.1 - 0.173\,S$	67	$771/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	8.4	42.0	$11.6 - 0.077\,S$	101	$39{,}048/S^2$

Table 2-10
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5052 – H34 **Sheet, Plate, Drawn Tube**

F_{ty} = 26 k/in^2 E = 10,200 k/in^2
F_{cy} = 24 k/in^2 k_t = 1
F_{tu} = 34 k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	17.4
axial tension stress on gross area	D.2a	15.8

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	15.8	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	20.5	18.9	see also F.4.2
round tubes	F.6.1	18.4	17.0	see also F.6.2
rods	F.7	20.5	18.9	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	34.9
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	23.2

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$14.3 - 0.091\,S$	104	$51{,}860\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$16.8 - 0.089\,S$	125	$87{,}857\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$16.8 - 0.172\,S^{1/2}$	4259	$23{,}833\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$26.7 - 0.495\,S$	36	$11{,}533\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$28.9 - 1.793\,S^{1/2}$	88	$19.3 - 0.762\,S^{1/2}$	250	$3{,}813\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	14.5	7.9	$20.1 - 0.700\,S$	19	$2{,}440\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	14.5	7.9	$20.1 - 0.700\,S$	14.3	$144\,/S$
flat elements supported on both edges	B.5.4.2	b/t	14.5	24.6	$20.1 - 0.224\,S$	45	$449\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	14.5	21.0	$16.8 - 0.107\,S$	104	$61{,}012\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	14.5	38.8	$19.3 - 0.762\,S^{1/2}$	250	$3{,}813\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	14.5	39.4	$20.1 - 0.140\,S$	72	$718\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	18.9	55.9	$26.7 - 0.140\,S$	96	$1{,}276\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	18.9	10.4	$26.7 - 0.753\,S$	24	$4{,}981\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	18.9	125.2	$26.7 - 0.062\,S$	214	$2{,}859\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	18.9	36.3	$26.7 - 0.215\,S$	62	$829\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	9.5	40.5	$13.3 - 0.094\,S$	94	$39{,}048\,/S^2$

Table 2-11
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5052 – H36 **Sheet**

$F_{ty} = 29$ k/in^2 $E = 10{,}200$ k/in^2
$F_{cy} = 26$ k/in^2 $k_t = 1$
$F_{tu} = 37$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	19.0
axial tension stress on gross area	D.2a	17.6

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	17.6	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	22.8	20.5	see also F.4.2
round tubes	F.6.1	20.6	18.4	see also F.6.2
rods	F.7	22.8	20.5	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	37.9
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	25.2

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$15.6 - 0.104\,S$	100	$51{,}860\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$18.3 - 0.102\,S$	120	$87{,}857\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$18.3 - 0.195\,S^{1/2}$	3910	$23{,}833\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$29.2 - 0.565\,S$	34	$11{,}533\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$31.5 - 2.005\,S^{1/2}$	83	$21.0 - 0.852\,S^{1/2}$	231	$3{,}813\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	15.8	7.7	$21.9 - 0.798\,S$	18	$2{,}440\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	15.8	7.7	$21.9 - 0.798\,S$	13.7	$150\,/S$
flat elements supported on both edges	B.5.4.2	b/t	15.8	24.0	$21.9 - 0.255\,S$	43	$469\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	15.8	20.8	$18.3 - 0.122\,S$	100	$61{,}012\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	15.8	37.6	$21.0 - 0.852\,S^{1/2}$	231	$3{,}813\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	15.8	38.5	$21.9 - 0.160\,S$	69	$751\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	20.5	54.5	$29.2 - 0.160\,S$	91	$1{,}333\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	20.5	10.1	$29.2 - 0.859\,S$	23	$4{,}981\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	20.5	122.1	$29.2 - 0.071\,S$	205	$2{,}988\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	20.5	35.4	$29.2 - 0.246\,S$	59	$866\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	10.5	39.1	$14.9 - 0.112\,S$	89	$39{,}048\,/S^2$

Table 2-12
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5083 – H116, H32, H321 | **Sheet and Plate (0.188 to 1.500 in. thick)**

$F_{ty} = 31$ k/in^2 | $E = 10{,}400$ k/in^2
$F_{cy} = 26$ k/in^2 | $k_t = 1$
$F_{tu} = 44$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**		
Axial Tension				
axial tension stress on net effective area	D.2b	22.6		
axial tension stress on gross area	D.2a	18.8		
Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	18.8	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	24.4	20.5	see also F.4.2
round tubes	F.6.1	22.0	18.4	see also F.6.2
rods	F.7	24.4	20.5	
Bearing				
bolts or rivets on holes	J.3.7a, J.4.7	45.1		
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	30.0		

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$15.6 - 0.103\,S$	101	$52{,}877/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$18.3 - 0.101\,S$	121	$89{,}580/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$18.3 - 0.193\,S^{1/2}$	3987	$24{,}300/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$29.2 - 0.559\,S$	35	$11{,}760/S^2$
round tubes local buckling	F.6.2	R_b/t	$31.5 - 1.992\,S^{1/2}$	84	$21.0 - 0.847\,S^{1/2}$	235	$3{,}888/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	15.8	7.8	$21.9 - 0.790\,S$	18	$2{,}488/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	15.8	7.8	$21.9 - 0.790\,S$	13.9	$152/S$
flat elements supported on both edges	B.5.4.2	b/t	15.8	24.3	$21.9 - 0.253\,S$	43	$474/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	15.8	21.0	$18.3 - 0.121\,S$	101	$62{,}208/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	15.8	38.1	$21.0 - 0.847\,S^{1/2}$	235	$3{,}888/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	15.8	38.8	$21.9 - 0.158\,S$	69	$758/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	20.5	55.0	$29.2 - 0.158\,S$	92	$1{,}346/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	20.5	10.2	$29.2 - 0.851\,S$	23	$5{,}078/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	20.5	123.3	$29.2 - 0.071\,S$	207	$3{,}017/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	20.5	35.8	$29.2 - 0.243\,S$	60	$875/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	11.3	38.7	$16.1 - 0.124\,S$	86	$39{,}813/S^2$

Table 2-13
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5086 – H34 **Sheet, Plate, Drawn Tube**

$F_{ty} = 34$ k/in^2
$F_{cy} = 32$ k/in^2
$F_{tu} = 44$ k/in^2
$E = 10{,}400$ k/in^2
$k_t = 1$

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**	
Axial Tension			
axial tension stress on net effective area	D.2b	22.6	
axial tension stress on gross area	D.2a	20.6	
Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	20.6	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	26.8	25.2 see also F.4.2
round tubes	F.6.1	24.1	22.7 see also F.6.2
rods	F.7	26.8	25.2
Bearing			
bolts or rivets on holes	J.3.7a, J.4.7	45.1	
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	30.0	

		Slenderness S	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
Axial Compression							
all shapes member buckling	E.3	kL/r			$19.4 - 0.143\ S$	90	$52{,}877\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$22.9 - 0.141\ S$	108	$89{,}580\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$22.9 - 0.270\ S^{1/2}$	3191	$24{,}300\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$36.7 - 0.788\ S$	31	$11{,}760\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$31.5 - 2.665\ S^{1/2}$	73	$26.1 - 1.132\ S^{1/2}$	192	$3{,}888\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	19.4	7.3	$27.5 - 1.112\ S$	16	$2{,}488\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	19.4	7.3	$27.5 - 1.112\ S$	12.4	$170\ /S$
flat elements supported on both edges	B.5.4.2	b/t	19.4	22.8	$27.5 - 0.356\ S$	39	$531\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	19.4	20.6	$22.9 - 0.169\ S$	90	$62{,}208\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	19.4	35.0	$26.1 - 1.132\ S^{1/2}$	192	$3{,}888\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	19.4	36.4	$27.5 - 0.222\ S$	62	$849\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	25.2	51.5	$36.7 - 0.223\ S$	82	$1{,}509\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	25.2	9.6	$36.7 - 1.199\ S$	20	$5{,}078\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	25.2	115.4	$36.7 - 0.099\ S$	185	$3{,}382\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	25.2	33.5	$36.7 - 0.343\ S$	54	$981\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	12.4	37.5	$17.8 - 0.145\ S$	82	$39{,}813\ /S^2$

Table 2-14
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5086 – H116	**Sheet and Plate**
5086 – H32	**Drawn Tube, Sheet and Plate**
$F_{ty} = 28$ k/in^2	$E = 10{,}400$ k/in^2
$F_{cy} = 26$ k/in^2	$k_t = 1$
$F_{tu} = 40$ k/in^2	

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**	
Axial Tension			
axial tension stress on net effective area	D.2b	20.5	
axial tension stress on gross area	D.2a	17.0	
Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	17.0	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	22.1	20.5 see also F.4.2
round tubes	F.6.1	19.9	18.4 see also F.6.2
rods	F.7	22.1	20.5
Bearing			
bolts or rivets on holes	J.3.7a, J.4.7	41.0	
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	27.3	

		Slenderness S	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
Axial Compression							
all shapes member buckling	E.3	kL/r			$15.6 - 0.103\ S$	101	$52{,}877\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$18.3 - 0.101\ S$	121	$89{,}580\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$18.3 - 0.193\ S^{1/2}$	3987	$24{,}300\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$29.2 - 0.559\ S$	35	$11{,}760\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$31.5 - 1.992\ S^{1/2}$	84	$21.0 - 0.847\ S^{1/2}$	235	$3{,}888\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	15.8	7.8	$21.9 - 0.790\ S$	18	$2{,}488\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	15.8	7.8	$21.9 - 0.790\ S$	13.9	$152\ /S$
flat elements supported on both edges	B.5.4.2	b/t	15.8	24.3	$21.9 - 0.253\ S$	43	$474\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	15.8	21.0	$18.3 - 0.121\ S$	101	$62{,}208\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	15.8	38.1	$21.0 - 0.847\ S^{1/2}$	235	$3{,}888\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	15.8	38.8	$21.9 - 0.158\ S$	69	$758\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	20.5	55.0	$29.2 - 0.158\ S$	92	$1{,}346\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	20.5	10.2	$29.2 - 0.851\ S$	23	$5{,}078\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	20.5	123.3	$29.2 - 0.071\ S$	207	$3{,}017\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	20.5	35.8	$29.2 - 0.243\ S$	60	$875\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	10.2	39.9	$14.4 - 0.105\ S$	91	$39{,}813\ /S^2$

Table 2-15
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5454 – H32 **Sheet and Plate**

F_{ty} = 26 k/in^2 E = 10,400 k/in^2
F_{cy} = 24 k/in^2 k_t = 1
F_{tu} = 36 k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	18.5
axial tension stress on gross area	D.2a	15.8

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	15.8	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	20.5	18.9	see also F.4.2
round tubes	F.6.1	18.4	17.0	see also F.6.2
rods	F.7	20.5	18.9	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	36.9
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	24.6

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			14.3 – 0.090 S	105	52,877 /S^2
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b{}^{1/2})$			16.8 – 0.089 S	127	89,580 /S^2
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			16.8 – 0.170 $S^{1/2}$	4343	24,300 /S
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			26.7 – 0.490 S	36	11,760 /S^2
round tubes local buckling	F.6.2	R_b/t	28.9 – 1.781 $S^{1/2}$	89	19.3 – 0.757 $S^{1/2}$	255	3,888 /[$S(1+S^{1/2}/35)^2$]
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	14.5	8.0	20.1 – 0.693 S	19	2,488 /S^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	14.5	8.0	20.1 – 0.693 S	14.5	145 /S
flat elements supported on both edges	B.5.4.2	b/t	14.5	24.9	20.1 – 0.222 S	45	453 /S
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	14.5	21.2	16.8 – 0.106 S	105	62,208 /S^2
curved elements supported on both edges	B.5.4.5	R_b/t	14.5	39.3	19.3 – 0.757 $S^{1/2}$	255	3,888 /[$S(1+S^{1/2}/35)^2$]
flat elements—alternate method	B.5.4.6	λ_{eq}	14.5	39.8	20.1 – 0.139 S	72	725 /S
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	18.9	56.4	26.7 – 0.139 S	96	1,288 /S
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	18.9	10.5	26.7 – 0.746 S	24	5,078 /S^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	18.9	126.4	26.7 – 0.062 S	216	2,887 /S
flat elements—alternate method	B.5.5.4	λ_{eq}	18.9	36.7	26.7 – 0.213 S	63	837 /S
Elements—Shear							
flat elements supported on both edges	G.2	b/t	9.5	40.8	13.3 – 0.093 S	95	39,813 /S^2

Table 2-16
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

5454 – H34 **Sheet and Plate**

$F_{ty} = 29$ k/in^2 $E = 10{,}400$ k/in^2
$F_{cy} = 27$ k/in^2 $k_t = 1$
$F_{tu} = 39$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	20.0
axial tension stress on gross area	D.2a	17.6

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	17.6	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	22.8	21.3 see also F.4.2
round tubes	F.6.1	20.6	19.1 see also F.6.2
rods	F.7	22.8	21.3

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	40.6
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	26.6

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$16.2 - 0.109\,S$	99	$52{,}877/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$19.1 - 0.107\,S$	119	$89{,}580/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$19.1 - 0.205\,S^{1/2}$	3829	$24{,}300/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$30.4 - 0.595\,S$	34	$11{,}760/S^2$
round tubes local buckling	F.6.2	R_b/t	$32.7 - 2.100\,S^{1/2}$	82	$21.8 - 0.893\,S^{1/2}$	227	$3{,}888/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	16.4	7.7	$22.8 - 0.841\,S$	18	$2{,}488/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	16.4	7.7	$22.8 - 0.841\,S$	13.6	$155/S$
flat elements supported on both edges	B.5.4.2	b/t	16.4	24.0	$22.8 - 0.269\,S$	42	$484/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	16.4	21.0	$19.1 - 0.128\,S$	99	$62{,}208/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	16.4	37.5	$21.8 - 0.893\,S^{1/2}$	227	$3{,}888/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	16.4	38.4	$22.8 - 0.168\,S$	68	$774/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	21.3	54.4	$30.4 - 0.168\,S$	90	$1{,}374/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	21.3	10.1	$30.4 - 0.906\,S$	22	$5{,}078/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	21.3	121.8	$30.4 - 0.075\,S$	203	$3{,}080/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	21.3	35.3	$30.4 - 0.259\,S$	59	$893/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	10.5	39.5	$14.9 - 0.111\,S$	89	$39{,}813/S^2$

Table 2-17
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6005A - T61 Extrusions (up through 1.000 in. thick)

$F_{ty} = 35$ k/in^2 $\quad E = 10{,}100$ k/in^2
$F_{cy} = 35$ k/in^2 $\quad k_t = 1$
$F_{tu} = 38$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	19.5
axial tension stress on gross area	D.2a	21.2

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	19.5	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	27.6	27.6 see also F.4.2
round tubes	F.6.1	24.2	24.8 see also F.6.2
rods	F.7	27.6	27.6

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	39.0
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	25.9

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$20.3 - 0.127\,S$	66	$51{,}352/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$23.9 - 0.124\,S$	79	$86{,}996/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$23.9 - 0.238\,S^{1/2}$	1685	$23{,}599/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$40.5 - 0.928\,S$	29	$11{,}420/S^2$
round tubes local buckling	F.6.2	R_b/t	$39.3 - 2.702\,S^{1/2}$	55	$26.2 - 0.944\,S^{1/2}$	141	$3{,}776/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	21.2	6.7	$27.3 - 0.910\,S$	12	$2{,}417/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	21.2	6.7	$27.3 - 0.910\,S$	10.5	$186/S$
flat elements supported on both edges	B.5.4.2	b/t	21.2	20.8	$27.3 - 0.291\,S$	33	$580/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	21.2	17.8	$23.9 - 0.149\,S$	66	$60{,}414/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	21.2	27.6	$26.2 - 0.944\,S^{1/2}$	141	$3{,}776/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	21.2	33.3	$27.3 - 0.182\,S$	52	$928/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	27.6	49.3	$40.5 - 0.262\,S$	77	$1{,}563/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	27.6	9.2	$40.5 - 1.412\,S$	19	$4{,}932/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	27.6	110.5	$40.5 - 0.117\,S$	173	$3{,}502/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	27.6	32.0	$40.5 - 0.403\,S$	50	$1{,}016/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	12.7	35.3	$16.5 - 0.107\,S$	63	$38{,}665/S^2$

Table 2-18
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6061 - T6 **Sheet, Rod & Bar, Drawn Tube**
6061 - T651 **Plate (Up thru 4.000 in. thick)**
F_{ty} = 35 k/in² E = 10,100 k/in²
F_{cy} = 35 k/in² k_t = 1
F_{tu} = 42 k/in²

Allowable Stresses F/Ω (k/in²)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	21.5
axial tension stress on gross area	D.2a	21.2

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	21.2	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	27.6	27.6 see also F.4.2
round tubes	F.6.1	24.8	24.8 see also F.6.2
rods	F.7	27.6	27.6
Bearing			
bolts or rivets on holes	J.3.7a, J.4.7	43.1	
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	28.6	

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			20.3 – 0.127 S	66	51,352 /S^2
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			23.9 – 0.124 S	79	86,996 /S^2
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			23.9 – 0.238 $S^{1/2}$	1685	23,599 /S
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			40.5 – 0.928 S	29	11,420 /S^2
round tubes local buckling	F.6.2	R_b/t	39.3 – 2.702 $S^{1/2}$	55	26.2 – 0.944 $S^{1/2}$	141	3,776 /[$S(1+S^{1/2}/35)^2$]
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	21.2	6.7	27.3 – 0.910 S	12	2,417 /S^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	21.2	6.7	27.3 – 0.910 S	10.5	186 /S
flat elements supported on both edges	B.5.4.2	b/t	21.2	20.8	27.3 – 0.291 S	33	580 /S
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	21.2	17.8	23.9 – 0.149 S	66	60,414 /S^2
curved elements supported on both edges	B.5.4.5	R_b/t	21.2	27.6	26.2 – 0.944 $S^{1/2}$	141	3,776 /[$S(1+S^{1/2}/35)^2$]
flat elements—alternate method	B.5.4.6	λ_{eq}	21.2	33.3	27.3 – 0.182 S	52	928 /S
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	27.6	49.3	40.5 – 0.262 S	77	1,563 /S
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	27.6	9.2	40.5 – 1.412 S	19	4,932 /S^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	27.6	110.5	40.5 – 0.117 S	173	3,502 /S
flat elements—alternate method	B.5.5.4	λ_{eq}	27.6	32.0	40.5 – 0.403 S	50	1,016 /S
Elements—Shear							
flat elements supported on both edges	G.2	b/t	12.7	35.3	16.5 – 0.107 S	63	38,665 /S^2

Table 2-19
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6061 – T6, T6510, T6511 **Extrusions**
6061 – T6 **Pipe**
6351 - T5 **Extrusions**
F_{ty} = 35 k/in² E = 10,100 k/in²
F_{cy} = 35 k/in² k_t = 1
F_{tu} = 38 k/in²

Allowable Stresses F/Ω (k/in²)	**Section**	**F/Ω**	
Axial Tension			
axial tension stress on net effective area	D.2b	19.5	
axial tension stress on gross area	D.2a	21.2	
Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	19.5	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	27.6	27.6 see also F.4.2
round tubes	F.6.1	24.2	24.8 see also F.6.2
rods	F.7	27.6	27.6
Bearing			
bolts or rivets on holes	J.3.7a, J.4.7	39.0	
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	25.9	

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			20.3 – 0.127 S	66	51,352 /S^2
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			23.9 – 0.124 S	79	86,996 /S^2
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			23.9 – 0.238 $S^{1/2}$	1685	23,599 /S
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			40.5 – 0.928 S	29	11,420 /S^2
round tubes local buckling	F.6.2	R_b/t	39.3 – 2.702 $S^{1/2}$	55	26.2 – 0.944 $S^{1/2}$	141	3,776 /[$S(1+S^{1/2}/35)^2$]
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	21.2	6.7	27.3 – 0.910 S	12	2,417 /S^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	21.2	6.7	27.3 – 0.910 S	10.5	186 /S
flat elements supported on both edges	B.5.4.2	b/t	21.2	20.8	27.3 – 0.291 S	33	580 /S
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	21.2	17.8	23.9 – 0.149 S	66	60,414 /S^2
curved elements supported on both edges	B.5.4.5	R_b/t	21.2	27.6	26.2 – 0.944 $S^{1/2}$	141	3,776 /[$S(1+S^{1/2}/35)^2$]
flat elements—alternate method	B.5.4.6	λ_{eq}	21.2	33.3	27.3 – 0.182 S	52	928 /S
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	27.6	49.3	40.5 – 0.262 S	77	1,563 /S
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	27.6	9.2	40.5 – 1.412 S	19	4,932 /S^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	27.6	110.5	40.5 – 0.117 S	173	3,502 /S
flat elements—alternate method	B.5.5.4	λ_{eq}	27.6	32.0	40.5 – 0.403 S	50	1,016 /S
Elements—Shear							
flat elements supported on both edges	G.2	b/t	12.7	35.3	16.5 – 0.107 S	63	38,665 /S^2

Table 2-20
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6063 – T5 **Extrusions (Up thru 0.500 in. thick)**
6063 – T52 **Extrusions (Up thru 1.000 in. thick)**

$F_{ty} = 16$ k/in^2
$F_{cy} = 16$ k/in^2
$F_{tu} = 22$ k/in^2
$E = 10{,}100$ k/in^2
$k_t = 1$

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	11.3
axial tension stress on gross area	D.2a	9.7

		Tension	**Compression**
Flexure			
elements in uniform stress	F.8.1.1	9.7	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	12.6	12.6 see also F.4.2
round tubes	F.6.1	11.3	11.3 see also F.6.2
rods	F.7	12.6	12.6

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	22.6
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	15.0

		Slenderness S	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
Axial Compression							
all shapes member buckling	E.3	kL/r			$8.9 - 0.037\ S$	99	$51{,}352\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$10.5 - 0.036\ S$	119	$86{,}996\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$10.5 - 0.070\ S^{1/2}$	3823	$23{,}599\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$17.2 - 0.256\ S$	45	$11{,}420\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$17.5 - 0.917\ S^{1/2}$	95	$11.6 - 0.320\ S^{1/2}$	275	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.7	8.2	$11.8 - 0.260\ S$	19	$2{,}417\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.7	8.2	$11.8 - 0.260\ S$	15.9	$122\ /S$
flat elements supported on both edges	B.5.4.2	b/t	9.7	25.6	$11.8 - 0.083\ S$	50	$382\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.7	18.8	$10.5 - 0.044\ S$	99	$60{,}414\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	9.7	36.7	$11.6 - 0.320\ S^{1/2}$	275	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	9.7	41.0	$11.8 - 0.052\ S$	80	$611\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	12.6	62.9	$17.2 - 0.072\ S$	119	$1{,}017\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	12.6	11.7	$17.2 - 0.389\ S$	29	$4{,}932\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	12.6	141.1	$17.2 - 0.032\ S$	266	$2{,}280\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	12.6	40.9	$17.2 - 0.111\ S$	77	$661\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	5.8	43.6	$7.2 - 0.031\ S$	96	$38{,}665\ /S^2$

Table 2-21
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6063 – T6 **Extrusions and Pipe**

F_{ty} = 25 k/in^2 E = 10,100 k/in^2
F_{cy} = 25 k/in^2 k_t = 1
F_{tu} = 30 k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**	
Axial Tension			
axial tension stress on net effective area	D.2b	15.4	
axial tension stress on gross area	D.2a	15.2	
		Tension	**Compression**
Flexure			
elements in uniform stress	F.8.1.1	15.2	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	19.7	19.7 see also F.4.2
round tubes	F.6.1	17.7	17.7 see also F.6.2
rods	F.7	19.7	19.7
Bearing			
bolts or rivets on holes	J.3.7a, J.4.7	30.8	
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	20.5	

		Slenderness S	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
Axial Compression							
all shapes member buckling	E.3	kL/r			14.2 – 0.074 S	78	51,352 $/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			16.7 – 0.073 S	94	86,996 $/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			16.7 – 0.140 $S^{1/2}$	2400	23,599 $/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			27.9 – 0.532 S	35	11,420 $/S^2$
round tubes local buckling	F.6.2	R_b/t	27.7 – 1.697 $S^{1/2}$	70	18.5 – 0.593 $S^{1/2}$	189	3,776 $/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	15.2	7.3	19.0 – 0.530 S	15	2,417 $/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	15.2	7.3	19.0 – 0.530 S	12.6	155 $/S$
flat elements supported on both edges	B.5.4.2	b/t	15.2	22.8	19.0 – 0.170 S	39	484 $/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	15.2	18.2	16.7 – 0.088 S	78	60,414 $/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	15.2	31.2	18.5 – 0.593 $S^{1/2}$	189	3,776 $/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	15.2	36.5	19.0 – 0.106 S	63	775 $/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	19.7	54.9	27.9 – 0.150 S	93	1,298 $/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	19.7	10.2	27.9 – 0.810 S	23	4,932 $/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	19.7	123.0	27.9 – 0.067 S	208	2,910 $/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	19.7	35.7	27.9 – 0.231 S	60	844 $/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	9.1	38.7	11.5 – 0.062 S	76	38,665 $/S^2$

Table 2-22
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6082 – T6, T6511 **Extrusions**

$F_{ty} = 38$ k/in^2 $E = 10{,}100$ k/in^2
$F_{cy} = 38$ k/in^2 $k_t = 1$
$F_{tu} = 45$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	23.1
axial tension stress on gross area	D.2a	23.0

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	23.0	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	29.9	29.9	see also F.4.2
round tubes	F.6.1	26.9	26.9	see also F.6.2
rods	F.7	29.9	29.9	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	46.2
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	30.7

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$22.1 - 0.144\,S$	63	$51{,}352\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$26.0 - 0.141\,S$	75	$86{,}996\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$26.0 - 0.271\,S^{1/2}$	1545	$23{,}599\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$44.4 - 1.064\,S$	28	$11{,}420\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$42.8 - 3.027\,S^{1/2}$	52	$28.5 - 1.058\,S^{1/2}$	131	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	23.0	6.5	$29.8 - 1.039\,S$	12	$2{,}417\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	23.0	6.5	$29.8 - 1.039\,S$	10.0	$194\,/S$
flat elements supported on both edges	B.5.4.2	b/t	23.0	20.3	$29.8 - 0.333\,S$	31	$606\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	23.0	17.6	$26.0 - 0.170\,S$	63	$60{,}414\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	23.0	26.8	$28.5 - 1.058\,S^{1/2}$	131	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	23.0	32.5	$29.8 - 0.208\,S$	50	$969\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	29.9	48.0	$44.4 - 0.301\,S$	74	$1{,}635\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	29.9	8.9	$44.4 - 1.619\,S$	18	$4{,}932\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	29.9	107.5	$44.4 - 0.134\,S$	165	$3{,}666\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	29.9	31.2	$44.4 - 0.463\,S$	48	$1{,}063\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	13.8	34.5	$18.0 - 0.122\,S$	60	$38{,}665\,/S^2$

Table 2-23
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

6351 – T6	**Extrusions**
$F_{ty} = 37$ k/in^2	$E = 10{,}100$ k/in^2
$F_{cy} = 37$ k/in^2	$k_t = 1$
$F_{tu} = 42$ k/in^2	

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**	
Axial Tension			
axial tension stress on net effective area	D.2b	21.5	
axial tension stress on gross area	D.2a	22.4	
Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	21.5	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	29.2	29.2 see also F.4.2
round tubes	F.6.1	26.2	26.2 see also F.6.2
rods	F.7	29.2	29.2
Bearing			
bolts or rivets on holes	J.3.7a, J.4.7	43.1	
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	28.6	

		Slenderness S	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
Axial Compression							
all shapes member buckling	E.3	kL/r			$21.5 - 0.138\ S$	64	$51{,}352\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$25.3 - 0.136\ S$	77	$86{,}996\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$25.3 - 0.260\ S^{1/2}$	1589	$23{,}599\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$43.1 - 1.018\ S$	28	$11{,}420\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$41.6 - 2.918\ S^{1/2}$	53	$27.7 - 1.020\ S^{1/2}$	134	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	22.4	6.6	$29.0 - 0.996\ S$	12	$2{,}417\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	22.4	6.6	$29.0 - 0.996\ S$	10.2	$191\ /S$
flat elements supported on both edges	B.5.4.2	b/t	22.4	20.5	$29.0 - 0.319\ S$	32	$597\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	22.4	17.7	$25.3 - 0.163\ S$	64	$60{,}414\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	22.4	27.1	$27.7 - 1.020\ S^{1/2}$	134	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	22.4	32.8	$29.0 - 0.199\ S$	51	$956\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	29.2	48.4	$43.1 - 0.288\ S$	75	$1{,}611\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	29.2	9.0	$43.1 - 1.549\ S$	19	$4{,}932\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	29.2	108.5	$43.1 - 0.128\ S$	168	$3{,}612\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	29.2	31.5	$43.1 - 0.442\ S$	49	$1{,}047\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	13.5	34.7	$17.5 - 0.117\ S$	61	$38{,}665\ /S^2$

Table 2-24
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (UNWELDED)

7005 – T53 **Extrusions**

F_{ty} = 44 k/in^2 E = 10,500 k/in^2
F_{cy} = 43 k/in^2 k_t = 1
F_{tu} = 50 k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**	
Axial Tension			
axial tension stress on net effective area	D.2b	25.6	
axial tension stress on gross area	D.2a	26.7	
		Tension	**Compression**
Flexure			
elements in uniform stress	F.8.1.1	25.6	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	34.7	33.9 see also F.4.2
round tubes	F.6.1	31.2	30.5 see also F.6.2
rods	F.7	34.7	33.9
Bearing			
bolts or rivets on holes	J.3.7a, J.4.7	51.3	
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	34.1	

		Slenderness S	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
Axial Compression							
all shapes member buckling	E.3	kL/r			$25.2 – 0.172\ S$	60	$53{,}386\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$29.7 – 0.169\ S$	72	$90{,}441\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$29.7 - 0.324\ S^{1/2}$	1409	$24{,}534\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$50.9 – 1.282\ S$	26	$11{,}873\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$48.6 – 3.547\ S^{1/2}$	49	$32.4 – 1.239\ S^{1/2}$	122	$3{,}925\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	26.1	6.4	$34.0 – 1.245\ S$	11	$2{,}512\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	26.1	6.4	$34.0 – 1.245\ S$	9.6	$211\ /S$
flat elements supported on both edges	B.5.4.2	b/t	26.1	20.0	$34.0 – 0.398\ S$	30	$660\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	26.1	17.8	$29.7 – 0.203\ S$	60	$62{,}807\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	26.1	26.3	$32.4 – 1.239\ S^{1/2}$	122	$3{,}925\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	26.1	32.0	$34.0 – 0.249\ S$	48	$1{,}056\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	33.9	46.9	$50.9 – 0.362\ S$	70	$1{,}786\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	33.9	8.7	$50.9 – 1.950\ S$	17	$5{,}127\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	33.9	105.2	$50.9 – 0.162\ S$	157	$4{,}003\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	33.9	30.5	$50.9 – 0.557\ S$	46	$1{,}161\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	16.0	33.7	$21.1 – 0.152\ S$	57	$40{,}196\ /S^2$

Table 2-1W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

1100 - H14 **Sheet, Plate, Drawn Tube**

F_{ty} = 3.5 k/in^2 E = 10,100 k/in^2
F_{cy} = 3.5 k/in^2 k_t = 1
F_{tu} = 11 k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	5.6
axial tension stress on gross area	D.2a	2.1

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	2.1	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	2.8	2.8 see also F.4.2
round tubes	F.6.1	2.5	2.5 see also F.6.2
rods	F.7	2.8	2.8

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	11.3
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	7.5

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$1.9 - 0.004\ S$	284	$51{,}352\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$2.2 - 0.004\ S$	341	$86{,}996\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$2.2 - 0.008\ S^{1/2}$	31534	$23{,}599\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$3.4 - 0.022\ S$	101	$11{,}420\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$3.9 - 0.124\ S^{1/2}$	332	$2.6 - 0.053\ S^{1/2}$	1379	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	2.1	13.3	$2.5 - 0.032\ S$	53	$2{,}417\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	2.1	13.3	$2.5 - 0.032\ S$	40.0	$51\ /S$
flat elements supported on both edges	B.5.4.2	b/t	2.1	41.6	$2.5 - 0.010\ S$	125	$159\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	2.1	23.8	$2.2 - 0.005\ S$	284	$60{,}414\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	2.1	80.1	$2.6 - 0.053\ S^{1/2}$	1379	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	2.1	66.6	$2.5 - 0.006\ S$	200	$255\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	2.8	95.8	$3.4 - 0.006\ S$	268	$450\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	2.8	17.8	$3.4 - 0.034\ S$	66	$4{,}932\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	2.8	214.8	$3.4 - 0.003\ S$	601	$1{,}008\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	2.8	62.3	$3.4 - 0.010\ S$	174	$292\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	1.3	70.5	$1.5 - 0.004\ S$	275	$38{,}665\ /S^2$

Table 2-2W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

3003 – H14 **Sheet, Plate, Drawn Tube**

$F_{ty} = 5$ k/in² $E = 10{,}100$ k/in²
$F_{cy} = 5$ k/in² $k_t = 1$
$F_{tu} = 14$ k/in²

Allowable Stresses F/Ω (k/in²)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	7.2
axial tension stress on gross area	D.2a	3.0

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	3.0	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	3.9	3.9 see also F.4.2
round tubes	F.6.1	3.5	3.5 see also F.6.2
rods	F.7	3.9	3.9

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	14.4
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	9.5

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$2.8 - 0.008\,S$	236	$51{,}352/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$3.2 - 0.008\,S$	284	$86{,}996/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$3.2 - 0.015\,S^{1/2}$	21836	$23{,}599/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$4.9 - 0.039\,S$	84	$11{,}420/S^2$
round tubes local buckling	F.6.2	R_b/t	$5.6 - 0.203\,S^{1/2}$	259	$3.8 - 0.086\,S^{1/2}$	1066	$3{,}776/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.0	12.2	$3.7 - 0.056\,S$	44	$2{,}417/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.0	12.2	$3.7 - 0.056\,S$	33.2	$61/S$
flat elements supported on both edges	B.5.4.2	b/t	3.0	38.0	$3.7 - 0.018\,S$	104	$192/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.0	23.4	$3.2 - 0.009\,S$	236	$60{,}414/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	3.0	70.3	$3.8 - 0.086\,S^{1/2}$	1066	$3{,}776/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	3.0	60.9	$3.7 - 0.011\,S$	166	$307/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	3.9	87.3	$4.9 - 0.011\,S$	222	$544/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	3.9	16.2	$4.9 - 0.060\,S$	55	$4{,}932/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	3.9	195.7	$4.9 - 0.005\,S$	497	$1{,}219/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	3.9	56.8	$4.9 - 0.017\,S$	144	$353/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	1.8	64.3	$2.2 - 0.007\,S$	228	$38{,}665/S^2$

Table 2-3W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

3003 – H16 **Sheet**

$F_{ty} = 5$ k/in^2 $E = 10{,}100$ k/in^2
$F_{cy} = 5$ k/in^2 $k_t = 1$
$F_{tu} = 14$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**	
Axial Tension			
axial tension stress on net effective area	D.2b	7.2	
axial tension stress on gross area	D.2a	3.0	
Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	3.0	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	3.9	3.9 see also F.4.2
round tubes	F.6.1	3.5	3.5 see also F.6.2
rods	F.7	3.9	3.9
Bearing			
bolts or rivets on holes	J.3.7a, J.4.7	14.4	
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	9.5	

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$2.8 - 0.008\,S$	236	$51{,}352\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$3.2 - 0.008\,S$	284	$86{,}996\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$3.2 - 0.015\,S^{1/2}$	21836	$23{,}599\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$4.9 - 0.039\,S$	84	$11{,}420\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$5.6 - 0.203\,S^{1/2}$	259	$3.8 - 0.086\,S^{1/2}$	1066	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.0	12.2	$3.7 - 0.056\,S$	44	$2{,}417\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.0	12.2	$3.7 - 0.056\,S$	33.2	$61\,/S$
flat elements supported on both edges	B.5.4.2	b/t	3.0	38.0	$3.7 - 0.018\,S$	104	$192\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.0	23.4	$3.2 - 0.009\,S$	236	$60{,}414\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	3.0	70.3	$3.8 - 0.086\,S^{1/2}$	1066	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	3.0	60.9	$3.7 - 0.011\,S$	166	$307\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	3.9	87.3	$4.9 - 0.011\,S$	222	$544\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	3.9	16.2	$4.9 - 0.060\,S$	55	$4{,}932\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	3.9	195.7	$4.9 - 0.005\,S$	497	$1{,}219\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	3.9	56.8	$4.9 - 0.017\,S$	144	$353\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	1.8	64.3	$2.2 - 0.007\,S$	228	$38{,}665\,/S^2$

Table 2-4W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

Alclad 3004 – H34 **Sheet**

$F_{ty} = 8$ k/in²
$F_{cy} = 8$ k/in²
$F_{tu} = 21$ k/in²
$E = 10{,}100$ k/in²
$k_t = 1$

Allowable Stresses F/Ω (k/in²)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	10.8
axial tension stress on gross area	D.2a	4.8

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	4.8	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	6.3	6.3	see also F.4.2
round tubes	F.6.1	5.7	5.7	see also F.6.2
rods	F.7	6.3	6.3	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	21.5
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	14.3

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$4.5 - 0.016\,S$	185	$51{,}352\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$5.3 - 0.016\,S$	222	$86{,}996\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$5.3 - 0.030\,S^{1/2}$	13413	$23{,}599\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$8.1 - 0.083\,S$	65	$11{,}420\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$9.2 - 0.389\,S^{1/2}$	187	$6.1 - 0.165\,S^{1/2}$	715	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	4.8	10.7	$6.1 - 0.119\,S$	34	$2{,}417\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	4.8	10.7	$6.1 - 0.119\,S$	25.8	$79\,/S$
flat elements supported on both edges	B.5.4.2	b/t	4.8	33.6	$6.1 - 0.038\,S$	81	$247\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	4.8	22.8	$5.3 - 0.019\,S$	185	$60{,}414\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	4.8	59.0	$6.1 - 0.165\,S^{1/2}$	715	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	4.8	53.7	$6.1 - 0.024S$	129	$395\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	6.3	76.9	$8.1 - 0.023\,S$	173	$699\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	6.3	14.3	$8.1 - 0.127\,S$	43	$4{,}932\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	6.3	172.3	$8.1 - 0.010\,S$	387	$1{,}567\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	6.3	50.0	$8.1 - 0.036\,S$	112	$455\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	2.9	56.7	$3.7 - 0.014\,S$	177	$38{,}665\,/S^2$

Table 2-5W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5005 – H14 **Sheet and Plate**

$F_{ty} = 5$ k/in^2
$F_{cy} = 5$ k/in^2
$F_{tu} = 15$ k/in^2
$E = 10{,}100$ k/in^2
$k_t = 1$

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	7.7
axial tension stress on gross area	D.2a	3.0

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	3.0	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	3.9	3.9	see also F.4.2
round tubes	F.6.1	3.5	3.5	see also F.6.2
rods	F.7	3.9	3.9	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	15.4
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	10.2

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$2.8 - 0.008\,S$	236	$51{,}352\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$3.2 - 0.008\,S$	284	$86{,}996\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$3.2 - 0.015\,S^{1/2}$	21836	$23{,}599\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$4.9 - 0.039\,S$	84	$11{,}420\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$5.6 - 0.203\,S^{1/2}$	259	$3.8 - 0.086\,S^{1/2}$	1066	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.0	12.2	$3.7 - 0.056\,S$	44	$2{,}417\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.0	12.2	$3.7 - 0.056\,S$	33.2	$61\,/S$
flat elements supported on both edges	B.5.4.2	b/t	3.0	38.0	$3.7 - 0.018\,S$	104	$192\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.0	23.4	$3.2 - 0.009\,S$	236	$60{,}414\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	3.0	70.3	$3.8 - 0.086\,S^{1/2}$	1066	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	3.0	60.9	$3.7 - 0.011\,S$	166	$307\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	3.9	87.3	$4.9 - 0.011\,S$	222	$544\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	3.9	16.2	$4.9 - 0.060\,S$	55	$4{,}932\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	3.9	195.7	$4.9 - 0.005\,S$	497	$1{,}219\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	3.9	56.8	$4.9 - 0.017\,S$	144	$353\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	1.8	64.3	$2.2 - 0.007\,S$	228	$38{,}665\,/S^2$

Table 2-6W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5005 – H32 **Sheet and Plate**

F_{ty} = 5 k/in^2
F_{cy} = 5 k/in^2
F_{tu} = 15 k/in^2
E = 10,100 k/in^2
k_t = 1

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	7.7
axial tension stress on gross area	D.2a	3.0

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	3.0	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	3.9	3.9 see also F.4.2
round tubes	F.6.1	3.5	3.5 see also F.6.2
rods	F.7	3.9	3.9

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	15.4
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	10.2

Axial Compression		**Slenderness S**	**F/Ω for $S \leq S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \geq S_2$**
all shapes member buckling	E.3	kL/r			$2.8 - 0.008\,S$	236	$51{,}352/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$3.2 - 0.008\,S$	284	$86{,}996/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$3.2 - 0.015\,S^{1/2}$	21836	$23{,}599/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$4.9 - 0.039\,S$	84	$11{,}420/S^2$
round tubes local buckling	F.6.2	R_b/t	$5.6 - 0.203\,S^{1/2}$	259	$3.8 - 0.086\,S^{1/2}$	1066	$3{,}776/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.0	12.2	$3.7 - 0.056\,S$	44	$2{,}417/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.0	12.2	$3.7 - 0.056\,S$	33.2	$61/S$
flat elements supported on both edges	B.5.4.2	b/t	3.0	38.0	$3.7 - 0.018\,S$	104	$192/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.0	23.4	$3.2 - 0.009\,S$	236	$60{,}414/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	3.0	70.3	$3.8 - 0.086\,S^{1/2}$	1066	$3{,}776/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	3.0	60.9	$3.7 - 0.011\,S$	166	$307/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	3.9	87.3	$4.9 - 0.011\,S$	222	$544/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	3.9	16.2	$4.9 - 0.060\,S$	55	$4{,}932/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	3.9	195.7	$4.9 - 0.005\,S$	497	$1{,}219/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	3.9	56.8	$4.9 - 0.017\,S$	144	$353/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	1.8	64.3	$2.2 - 0.007\,S$	228	$38{,}665/S^2$

Table 2-7W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5005 – H34 **Sheet and Plate**

$F_{ty} = 5$ k/in^2 $E = 10{,}100$ k/in^2
$F_{cy} = 5$ k/in^2 $k_t = 1$
$F_{tu} = 15$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	7.7
axial tension stress on gross area	D.2a	3.0

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	3.0	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	3.9	3.9	see also F.4.2
round tubes	F.6.1	3.5	3.5	see also F.6.2
rods	F.7	3.9	3.9	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	15.4
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	10.2

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$2.8 - 0.008\,S$	236	$51{,}352\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$3.2 - 0.008\,S$	284	$86{,}996\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$3.2 - 0.015\,S^{1/2}$	21836	$23{,}599\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$4.9 - 0.039\,S$	84	$11{,}420\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$5.6 - 0.203\,S^{1/2}$	259	$3.8 - 0.086\,S^{1/2}$	1066	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.0	12.2	$3.7 - 0.056\,S$	44	$2{,}417\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.0	12.2	$3.7 - 0.056\,S$	33.2	$61\,/S$
flat elements supported on both edges	B.5.4.2	b/t	3.0	38.0	$3.7 - 0.018\,S$	104	$192\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.0	23.4	$3.2 - 0.009\,S$	236	$60{,}414\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	3.0	70.3	$3.8 - 0.086\,S^{1/2}$	1066	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	3.0	60.9	$3.7 - 0.011\,S$	166	$307\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	3.9	87.3	$4.9 - 0.011\,S$	222	$544\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	3.9	16.2	$4.9 - 0.060\,S$	55	$4{,}932\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	3.9	195.7	$4.9 - 0.005\,S$	497	$1{,}219\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	3.9	56.8	$4.9 - 0.017\,S$	144	$353\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	1.8	64.3	$2.2 - 0.007\,S$	228	$38{,}665\,/S^2$

Table 2-8W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5050 – H34 **Sheet**

F_{ty} = 6 k/in^2
F_{cy} = 6 k/in^2
F_{tu} = 18 k/in^2
E = 10,100 k/in^2
k_t = 1

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	9.2
axial tension stress on gross area	D.2a	3.6

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	3.6	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	4.7	4.7 see also F.4.2
round tubes	F.6.1	4.3	4.3 see also F.6.2
rods	F.7	4.7	4.7

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	18.5
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	12.3

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			3.3 – 0.010 S	215	51,352 /S^2
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			3.9 – 0.010 S	258	86,996 /S^2
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			3.9 – 0.019 $S^{1/2}$	18082	23,599 /S
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			6.0 – 0.052 S	76	11,420 /S^2
round tubes local buckling	F.6.2	R_b/t	6.8 – 0.261 $S^{1/2}$	228	4.5 – 0.111 $S^{1/2}$	932	3,776 /[$S(1+S^{1/2}/35)^2$]
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	3.6	11.6	4.5 – 0.075 S	40	2,417 /S^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	3.6	11.6	4.5 – 0.075 S	30.1	68 /S
flat elements supported on both edges	B.5.4.2	b/t	3.6	36.3	4.5 – 0.024 S	94	212 /S
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	3.6	23.2	3.9 – 0.012 S	215	60,414 /S^2
curved elements supported on both edges	B.5.4.5	R_b/t	3.6	65.7	4.5 – 0.111 $S^{1/2}$	932	3,776 /[$S(1+S^{1/2}/35)^2$]
flat elements—alternate method	B.5.4.6	λ_{eq}	3.6	58.0	4.5 – 0.015 S	150	339 /S
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	4.7	83.2	6.0 – 0.015 S	201	599 /S
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	4.7	15.4	6.0 – 0.080 S	50	4,932 /S^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	4.7	186.4	6.0 – 0.007 S	451	1,343 /S
flat elements—alternate method	B.5.5.4	λ_{eq}	4.7	54.1	6.0 – 0.023 S	131	390 /S
Elements—Shear							
flat elements supported on both edges	G.2	b/t	2.2	61.3	2.7 – 0.009 S	207	38,665 /S^2

Table 2-9W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5052 – H32 **Sheet, Plate, Drawn Tube**

$F_{ty} = 9.5$ k/in^2 $E = 10{,}200$ k/in^2
$F_{cy} = 9.5$ k/in^2 $k_t = 1$
$F_{tu} = 25$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
<u>Axial Tension</u>		
axial tension stress on net effective area	D.2b	12.8
axial tension stress on gross area	D.2a	5.8

<u>Flexure</u>		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	5.8	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	7.5	7.5 see also F.4.2
round tubes	F.6.1	6.7	6.7 see also F.6.2
rods	F.7	7.5	7.5

<u>Bearing</u>		
bolts or rivets on holes	J.3.7a, J.4.7	25.6
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	17.1

<u>Axial Compression</u>		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$5.4 - 0.021\,S$	170	$51{,}860/S^2$
<u>Flexural Compression</u>							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$6.3 - 0.021\,S$	204	$87{,}857/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$6.3 - 0.040\,S^{1/2}$	11323	$23{,}833/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$9.8 - 0.109\,S$	60	$11{,}533/S^2$
round tubes local buckling	F.6.2	R_b/t	$11.0 - 0.492\,S^{1/2}$	167	$7.3 - 0.209\,S^{1/2}$	608	$3{,}813/[S(1+S^{1/2}/35)^2]$
<u>Elements—Uniform Compression</u>							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	5.8	10.3	$7.4 - 0.156\,S$	32	$2{,}440/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	5.8	10.3	$7.4 - 0.156\,S$	23.7	$87/S$
flat elements supported on both edges	B.5.4.2	b/t	5.8	32.2	$7.4 - 0.050\,S$	74	$272/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	5.8	22.7	$6.3 - 0.025\,S$	170	$61{,}012/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	5.8	55.6	$7.3 - 0.209\,S^{1/2}$	608	$3{,}813/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	5.8	51.5	$7.4 - 0.031\,S$	118	$435/S$
<u>Elements—Flexural Compression</u>							
flat elements supported on both edges	B.5.5.1	b/t	7.5	73.6	$9.8 - 0.031\,S$	158	$771/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	7.5	13.7	$9.8 - 0.166\,S$	39	$4{,}981/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	7.5	165.0	$9.8 - 0.014\,S$	354	$1{,}728/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	7.5	47.8	$9.8 - 0.047\,S$	103	$501/S$
<u>Elements—Shear</u>							
flat elements supported on both edges	G.2	b/t	3.5	54.4	$4.4 - 0.018\,S$	162	$39{,}048/S^2$

Table 2-10W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5052 – H34 **Sheet, Plate, and Drawn Tube**

$F_{ty} = 9.5$ k/in^2 $E = 10{,}200$ k/in^2
$F_{cy} = 9.5$ k/in^2 $k_t = 1$
$F_{tu} = 25$ k/in^2

Allowable Stresses F/Ω (k/in^2)	Section	F/Ω
Axial Tension		
axial tension stress on net effective area	D.2b	12.8
axial tension stress on gross area	D.2a	5.8

Flexure		Tension	Compression	
elements in uniform stress	F.8.1.1	5.8	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	7.5	7.5	see also F.4.2
round tubes	F.6.1	6.7	6.7	see also F.6.2
rods	F.7	7.5	7.5	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	25.6
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	17.1

Axial Compression		Slenderness S	F/Ω for $S \le S_1$	S_1	F/Ω for $S_1 < S < S_2$	S_2	F/Ω for $S \ge S_2$
all shapes member buckling	E.3	kL/r			$5.4 - 0.021\ S$	170	$51{,}860\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$6.3 - 0.021\ S$	204	$87{,}857\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$6.3 - 0.040\ S^{1/2}$	11323	$23{,}833\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$9.8 - 0.109\ S$	60	$11{,}533\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$11.0 - 0.492\ S^{1/2}$	167	$7.3 - 0.209\ S^{1/2}$	608	$3{,}813\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	5.8	10.3	$7.4 - 0.156\ S$	32	$2{,}440\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	5.8	10.3	$7.4 - 0.156\ S$	23.7	$87\ /S$
flat elements supported on both edges	B.5.4.2	b/t	5.8	32.2	$7.4 - 0.050\ S$	74	$272\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	5.8	22.7	$6.3 - 0.025\ S$	170	$61{,}012\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	5.8	55.6	$7.3 - 0.209\ S^{1/2}$	608	$3{,}813\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	5.8	51.5	$7.4 - 0.031\ S$	118	$435\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	7.5	73.6	$9.8 - 0.031\ S$	158	$771\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	7.5	13.7	$9.8 - 0.166\ S$	39	$4{,}981\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	7.5	165.0	$9.8 - 0.014\ S$	354	$1{,}728\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	7.5	47.8	$9.8 - 0.047\ S$	103	$501\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	3.5	54.4	$4.4 - 0.018\ S$	162	$39{,}048\ /S^2$

Table 2-11W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5052 – H36	**Sheet**
$F_{ty} = 9.5$ k/in^2	$E = 10{,}200$ k/in^2
$F_{cy} = 9.5$ k/in^2	$k_t = 1$
$F_{tu} = 25$ k/in^2	

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**		
Axial Tension				
axial tension stress on net effective area	D.2b	12.8		
axial tension stress on gross area	D.2a	5.8		
Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	5.8	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	7.5	7.5	see also F.4.2
round tubes	F.6.1	6.7	6.7	see also F.6.2
rods	F.7	7.5	7.5	
Bearing				
bolts or rivets on holes	J.3.7a, J.4.7	25.6		
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	17.1		

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$5.4 - 0.021\,S$	170	$51{,}860\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$6.3 - 0.021\,S$	204	$87{,}857\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$6.3 - 0.040\,S^{1/2}$	11323	$23{,}833\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$9.8 - 0.109\,S$	60	$11{,}533\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$21.4 - 0.492\,S^{1/2}$	167	$7.3 - 0.209\,S^{1/2}$	608	$3{,}813\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	5.8	10.3	$7.4 - 0.156\,S$	32	$2{,}440\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	5.8	10.3	$7.4 - 0.156\,S$	23.7	$87\,/S$
flat elements supported on both edges	B.5.4.2	b/t	5.8	32.2	$7.4 - 0.050\,S$	74	$272\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	5.8	22.7	$6.3 - 0.025\,S$	170	$61{,}012\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	5.8	55.6	$7.3 - 0.209\,S^{1/2}$	608	$3{,}813\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	5.8	51.5	$7.4 - 0.031\,S$	118	$435\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	7.5	73.6	$9.8 - 0.031\,S$	158	$771\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	7.5	13.7	$9.8 - 0.166\,S$	39	$4{,}981\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	7.5	165.0	$9.8 - 0.014\,S$	354	$1{,}728\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	7.5	47.8	$9.8 - 0.047\,S$	103	$501\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	3.5	54.4	$4.4 - 0.018\,S$	162	$39{,}048\,/S^2$

Table 2-12W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5083 – H116, H32, H321
F_{ty} = 18 k/in^2
F_{cy} = 18 k/in^2
F_{tu} = 40 k/in^2

Sheet and Plate (0.188 to 1.500 in. thick)
E = 10,400 k/in^2
k_t = 1

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**		
Axial Tension				
axial tension stress on net effective area	D.2b	20.5		
axial tension stress on gross area	D.2a	10.9		
Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	10.9	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	14.2	14.2	see also F.4.2
round tubes	F.6.1	12.8	12.8	see also F.6.2
rods	F.7	14.2	14.2	
Bearing				
bolts or rivets on holes	J.3.7a, J.4.7	41.0		
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	27.3		

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$10.5 - 0.057\,S$	123	$52{,}877/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$12.4 - 0.056\,S$	147	$89{,}580/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$12.4 - 0.107\,S^{1/2}$	5896	$24{,}300/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$19.5 - 0.306\,S$	43	$11{,}760/S^2$
round tubes local buckling	F.6.2	R_b/t	$21.4 - 1.191\,S^{1/2}$	108	$14.3 - 0.506\,S^{1/2}$	336	$3{,}888/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	10.9	8.7	$14.7 - 0.433\,S$	23	$2{,}488/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	10.9	8.7	$14.7 - 0.433\,S$	16.9	$124/S$
flat elements supported on both edges	B.5.4.2	b/t	10.9	27.1	$14.7 - 0.139\,S$	53	$388/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	10.9	21.8	$12.4 - 0.067\,S$	123	$62{,}208/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	10.9	44.0	$14.3 - 0.506\,S^{1/2}$	336	$3{,}888/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	10.9	43.4	$14.7 - 0.087\,S$	85	$620/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	14.2	61.6	$19.5 - 0.086\,S$	113	$1{,}100/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	14.2	11.4	$19.5 - 0.465\,S$	28	$5{,}078/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	14.2	138.2	$19.5 - 0.039\,S$	253	$2{,}467/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	14.2	40.1	$19.5 - 0.133\,S$	73	$715/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	6.5	45.7	$8.9 - 0.051\,S$	116	$39{,}813/S^2$

Table 2-13W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5086 – H34 **Sheet, Plate, and Drawn Tube**

F_{ty} = 14 k/in² E = 10,400 k/in²
F_{cy} = 14 k/in² k_t = 1
F_{tu} = 35 k/in²

Allowable Stresses F/Ω (k/in²)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	17.9
axial tension stress on gross area	D.2a	8.5

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	8.5	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	11.0	11.0 see also F.4.2
round tubes	F.6.1	9.9	9.9 see also F.6.2
rods	F.7	11.0	11.0

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	35.9
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	23.9

		Slenderness S	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
Axial Compression							
all shapes member buckling	E.3	kL/r			$8.1 - 0.038\,S$	140	$52{,}877/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$9.5 - 0.038\,S$	168	$89{,}580/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$9.5 - 0.072\,S^{1/2}$	7688	$24{,}300/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$14.8 - 0.203\,S$	49	$11{,}760/S^2$
round tubes local buckling	F.6.2	R_b/t	$16.5 - 0.839\,S^{1/2}$	129	$11.0 - 0.357\,S^{1/2}$	427	$3{,}888/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	8.5	9.3	$11.2 - 0.288\,S$	26	$2{,}488/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	8.5	9.3	$11.2 - 0.288\,S$	19.4	$108/S$
flat elements supported on both edges	B.5.4.2	b/t	8.5	29.2	$11.2 - 0.092\,S$	61	$338/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	8.5	22.3	$9.5 - 0.045\,S$	140	$62{,}208/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	8.5	48.5	$11.0 - 0.357\,S^{1/2}$	427	$3{,}888/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	8.5	46.7	$11.2 - 0.058\,S$	97	$541/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	11.0	66.5	$14.8 - 0.057\,S$	129	$960/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	11.0	12.3	$14.8 - 0.309\,S$	32	$5{,}078/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	11.0	148.9	$14.8 - 0.026\,S$	290	$2{,}151/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	11.0	43.2	$14.8 - 0.088\,S$	84	$624/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	5.1	49.2	$6.8 - 0.034\,S$	133	$39{,}813/S^2$

Table 2-14W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5086 – H116 **Sheet and Plate**
5086 – H32 **Sheet and Plate, Drawn Tube**

F_{ty} = 14 k/in² E = 10,400 k/in²
F_{cy} = 14 k/in² k_t = 1
F_{tu} = 35 k/in²

Allowable Stresses F/Ω (k/in²)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	17.9
axial tension stress on gross area	D.2a	8.5

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	8.5	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	11.0	11.0 see also F.4.2
round tubes	F.6.1	9.9	9.9 see also F.6.2
rods	F.7	11.0	11.0

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	35.9
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	23.9

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$8.1 - 0.038\,S$	140	$52{,}877/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$9.5 - 0.038\,S$	168	$89{,}580/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$9.5 - 0.072\,S^{1/2}$	7688	$24{,}300/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$14.8 - 0.203\,S$	49	$11{,}760/S^2$
round tubes local buckling	F.6.2	R_b/t	$16.5 - 0.839\,S^{1/2}$	129	$11.0 - 0.357\,S^{1/2}$	427	$3{,}888/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	8.5	9.3	$11.2 - 0.288\,S$	26	$2{,}488/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	8.5	9.3	$11.2 - 0.288\,S$	19.4	$108/S$
flat elements supported on both edges	B.5.4.2	b/t	8.5	29.2	$11.2 - 0.092\,S$	61	$338/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	8.5	22.3	$9.5 - 0.045\,S$	140	$62{,}208/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	8.5	48.5	$11.0 - 0.357\,S^{1/2}$	427	$3{,}888/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	8.5	46.7	$11.2 - 0.058\,S$	97	$541/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	11.0	66.5	$14.8 - 0.057\,S$	129	$960/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	11.0	12.3	$14.8 - 0.309\,S$	32	$5{,}078/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	11.0	148.9	$14.8 - 0.026\,S$	290	$2{,}151/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	11.0	43.2	$14.8 - 0.088\,S$	84	$624/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	5.1	49.2	$6.8 - 0.034\,S$	133	$39{,}813/S^2$

Table 2-15W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5454 – H32 **Sheet and Plate**

$F_{ty} = 12$ k/in^2 $E = 10{,}400$ k/in^2
$F_{cy} = 12$ k/in^2 $k_t = 1$
$F_{tu} = 31$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	15.9
axial tension stress on gross area	D.2a	7.3

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	7.3	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	9.5	9.5	see also F.4.2
round tubes	F.6.1	8.5	8.5	see also F.6.2
rods	F.7	9.5	9.5	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	31.8
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	21.1

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$6.9 - 0.030S$	152	$52{,}877/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$8.1 - 0.029S$	183	$889{,}580/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$8.1 - 0.057S^{1/2}$	9041	$24{,}300/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$12.6 - 0.158S$	53	$11{,}760/S^2$
round tubes local buckling	F.6.2	R_b/t	$14.0 - 0.677S^{1/2}$	144	$9.3 - 0.288S^{1/2}$	495	$3{,}888/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	7.3	9.8	$9.5 - 0.224S$	28	$2{,}488/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	7.3	9.8	$9.5 - 0.224S$	21.1	$100/S$
flat elements supported on both edges	B.5.4.2	b/t	7.3	30.5	$9.5 - 0.072S$	66	$311/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	7.3	22.5	$8.1 - 0.035S$	152	$62{,}208/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	7.3	51.5	$9.3 - 0.288S^{1/2}$	495	$3{,}888/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	7.3	48.8	$9.5 - 0.045S$	105	$498/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	9.5	69.5	$12.6 - 0.045S$	141	$883/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	9.5	12.9	$12.6 - 0.240S$	35	$5{,}078/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	9.5	155.8	$12.6 - 0.020S$	315	$1{,}979/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	9.5	45.2	$12.6 - 0.069S$	91	$574/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	4.4	51.4	$5.7 - 0.026S$	145	$39{,}813/S^2$

Table 2-16W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

5454 – H34 **Sheet and Plate**

$F_{ty} = 12$ k/in^2 $E = 10{,}400$ k/in^2
$F_{cy} = 12$ k/in^2 $k_t = 1$
$F_{tu} = 31$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	15.9
axial tension stress on gross area	D.2a	7.3

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	7.3	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	9.5	9.5	see also F.4.2
round tubes	F.6.1	8.5	8.5	see also F.6.2
rods	F.7	9.5	9.5	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	31.8
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	21.1

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$6.9 - 0.030\,S$	152	$52{,}877\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$8.1 - 0.029\,S$	183	$889{,}580\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$8.1 - 0.057\,S^{1/2}$	9041	$24{,}300\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$12.6 - 0.158\,S$	53	$11{,}760\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$14.0 - 0.677\,S^{1/2}$	144	$9.3 - 0.288\,S^{1/2}$	495	$3{,}888\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	7.3	9.8	$9.5 - 0.224\,S$	28	$2{,}488\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	7.3	9.8	$9.5 - 0.224\,S$	21.1	$100\,/S$
flat elements supported on both edges	B.5.4.2	b/t	7.3	30.5	$9.5 - 0.072\,S$	66	$311\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	7.3	22.5	$8.1 - 0.035\,S$	152	$62{,}208\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	7.3	51.5	$9.3 - 0.288\,S^{1/2}$	495	$3{,}888\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	7.3	48.8	$9.5 - 0.045\,S$	105	$498\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	9.5	69.5	$12.6 - 0.045\,S$	141	$883\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	9.5	12.9	$12.6 - 0.240\,S$	35	$5{,}078\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	9.5	155.8	$12.6 - 0.020\,S$	315	$1{,}979\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	9.5	45.2	$12.6 - 0.069\,S$	91	$574\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	4.4	51.4	$5.7 - 0.026\,S$	145	$39{,}813\,/S^2$

Table 2-17W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

6005A - T61 Extrusions (up through 1.000 in. thick)

F_{ty} = 13 k/in^2 E = 10,100 k/in^2
F_{cy} = 13 k/in^2 k_t = 1
F_{tu} = 24 k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	12.3
axial tension stress on gross area	D.2a	7.9

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	7.9	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	10.2	10.2 see also F.4.2
round tubes	F.6.1	9.2	9.2 see also F.6.2
rods	F.7	10.2	10.2

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	24.6
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	16.4

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$7.5 - 0.035\,S$	144	$51{,}352/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$8.8 - 0.034\,S$	172	$86{,}996/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$8.8 - 0.065\,S^{1/2}$	8072	$23{,}599/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$13.7 - 0.182\,S$	50	$11{,}420/S^2$
round tubes local buckling	F.6.2	R_b/t	$15.2 - 0.764\,S^{1/2}$	133	$10.2 - 0.325\,S^{1/2}$	446	$3{,}776/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	7.9	9.4	$10.3 - 0.259\,S$	27	$2{,}417/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	7.9	9.4	$10.3 - 0.259\,S$	19.9	$103/S$
flat elements supported on both edges	B.5.4.2	b/t	7.9	29.4	$10.3 - 0.083\,S$	62	$320/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	7.9	22.1	$8.8 - 0.041\,S$	144	$60{,}414/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	7.9	49.0	$10.2 - 0.325\,S^{1/2}$	446	$3{,}776/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	7.9	47.0	$10.3 - 0.052\,S$	99	$513/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	10.2	66.9	$13.7 - 0.052\,S$	133	$909/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	10.2	12.4	$13.7 - 0.278\,S$	33	$4{,}932/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	10.2	150.0	$13.7 - 0.023\,S$	298	$2{,}037/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	10.2	43.5	$13.7 - 0.079\,S$	86	$591/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	4.7	49.5	$6.2 - 0.030\,S$	136	$38{,}665/S^2$

Table 2-18W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**	**6061 – T6, T651, T6510, T6511**	**All Products (See note)**
Axial Tension			F_{ty} = 11 k/in^2 F_{cy} = 11 k/in^2 F_{tu} = 24 k/in^2	E = 10,100 k/in^2 k_t = 1
axial tension stress on net effective area	D.2b	12.3		
axial tension stress on gross area	D.2a	6.7		

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	6.7	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	8.7	8.7 see also F.4.2
round tubes	F.6.1	7.8	7.8 see also F.6.2
rods	F.7	8.7	8.7

Note
Welded with 4043, 5554, or 5654 and > 0.375” thick

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	24.6
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	16.4

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			6.3 – 0.027 S	157	51,352 /S^2
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			7.4 – 0.026 S	188	86,996 /S^2
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			7.4 – 0.050 $S^{1/2}$	9618	23,599 /S
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			11.4 – 0.139 S	55	11,420 /S^2
round tubes local buckling	F.6.2	R_b/t	12.8 – 0.606 $S^{1/2}$	150	8.5 – 0.257 $S^{1/2}$	524	3,776 /[$S(1+S^{1/2}/35)^2$]
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	6.7	9.8	8.6 – 0.198 S	29	2,417 /S^2
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	6.7	9.8	8.6 – 0.198 S	21.8	94 /S
flat elements supported on both edges	B.5.4.2	b/t	6.7	30.8	8.6 – 0.063 S	68	293 /S
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	6.7	22.3	7.4 – 0.031 S	157	60,414 /S^2
curved elements supported on both edges	B.5.4.5	R_b/t	6.7	52.2	8.5 – 0.257 $S^{1/2}$	524	3,776 /[$S(1+S^{1/2}/35)^2$]
flat elements—alternate method	B.5.4.6	λ_{eq}	6.7	49.2	8.6 – 0.040 S	109	468 /S
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	8.7	70.3	11.4 – 0.039 S	145	830 /S
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	8.7	13.0	11.4 – 0.212 S	36	4,932 /S^2
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	8.7	157.5	11.4 – 0.018 S	326	1,861 /S
flat elements—alternate method	B.5.5.4	λ_{eq}	8.7	45.7	11.4 – 0.060 S	94	540 /S
Elements—Shear							
flat elements supported on both edges	G.2	b/t	4.0	51.9	5.2 – 0.023 S	149	38,665/S^2

Table 2-19W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	12.3
axial tension stress on gross area	D.2a	9.1

6061 – T6, T6510, T6511

F_{ty} = 15 k/in^2
F_{cy} = 15 k/in^2
F_{tu} = 24 k/in^2

All Products (See note)

E = 10,100 k/in^2
k_t = 1

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	9.1	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	11.8	11.8 see also F.4.2
round tubes	F.6.1	10.6	10.6 see also F.6.2
rods	F.7	11.8	11.8

Note:
Welded with 5183, 5356, or 5556, or Welded with 4043, 5554, or 5654 and ≤0.375” thick

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	24.6
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	16.4

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$8.7 - 0.043\ S$	133	$51{,}352\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$10.2 - 0.043\ S$	160	$86{,}996\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$10.2 - 0.082\ S^{1/2}$	6943	$23{,}599\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$16.0 - 0.230\ S$	46	$11{,}420\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$17.7 - 0.933\ S^{1/2}$	121	$11.8 - 0.396S^{1/2}$	390	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.1	9.0	$12.0 - 0.327\ S$	25	$2{,}417\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.1	9.0	$12.0 - 0.327\ S$	18.4	$111\ /S$
flat elements supported on both edges	B.5.4.2	b/t	9.1	28.2	$12.0 - 0.105\ S$	58	$346\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.1	21.8	$10.2 - 0.051\ S$	133	$60{,}414\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	9.1	46.4	$11.8 - 0.396\ S^{1/2}$	390	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	9.1	45.1	$12.0 - 0.065\ S$	92	$554\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	11.8	64.2	$16.0 - 0.065\ S$	123	$982\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	11.8	11.9	$16.0 - 0.350\ S$	30	$4{,}932\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	11.8	143.8	$16.0 - 0.029\ S$	275	$2{,}201\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	11.8	41.7	$16.0 - 0.0100\ S$	80	$638\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	5.5	47.5	$7.3 - 0.038\ S$	126	$38{,}665\ /S^2$

Table 2-20W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

6063 – T5 **Extrusions (Up thru 0.500 in. thick)**
6063 – T52 **Extrusions (Up thru 1.000 in. thick)**

$F_{ty} = 8$ k/in^2 $E = 10{,}100$ k/in^2
$F_{cy} = 8$ k/in^2 $k_t = 1$
$F_{tu} = 17$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	8.7
axial tension stress on gross area	D.2a	4.8

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	4.8	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	6.3	6.3	see also F.4.2
round tubes	F.6.1	5.7	5.7	see also F.6.2
rods	F.7	6.3	6.3	

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	17.4
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	11.6

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$4.5 - 0.016\,S$	185	$51{,}352\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$5.3 - 0.016\,S$	222	$86{,}996\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$5.3 - 0.030\,S^{1/2}$	13413	$23{,}599\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$8.1 - 0.083\,S$	65	$11{,}420\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$9.2 - 0.389\,S^{1/2}$	187	$6.1 - 0.165\,S^{1/2}$	715	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	4.8	10.7	$6.1 - 0.119\,S$	34	$2{,}417\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	4.8	10.7	$6.1 - 0.119\,S$	25.8	$79\,/S$
flat elements supported on both edges	B.5.4.2	b/t	4.8	33.6	$6.1 - 0.038\,S$	81	$247\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	4.8	22.8	$5.3 - 0.019\,S$	185	$60{,}414\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	4.8	59.0	$6.1 - 0.165\,S^{1/2}$	715	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	4.8	53.7	$6.1 - 0.024\,S$	129	$395\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	6.3	76.9	$8.1 - 0.023\,S$	173	$699\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	6.3	14.3	$8.1 - 0.127\,S$	43	$4{,}932\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	6.3	172.3	$8.1 - 0.010\,S$	387	$1{,}567\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	6.3	50.0	$8.1 - 0.036\,S$	112	$455\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	2.9	56.7	$3.7 - 0.014\,S$	177	$38{,}665\,/S^2$

Table 2-21W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

6063 – T6 **Extrusions and Pipe**

$F_{ty} = 8$ k/in^2 $E = 10{,}100$ k/in^2
$F_{cy} = 8$ k/in^2 $k_t = 1$
$F_{tu} = 17$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	8.7
axial tension stress on gross area	D.2a	4.8

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	4.8	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	6.3	6.3 see also F.4.2
round tubes	F.6.1	5.7	5.7 see also F.6.2
rods	F.7	6.3	6.3

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	17.4
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	11.6

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$4.5 - 0.016\,S$	185	$51{,}352\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$5.3 - 0.016\,S$	222	$86{,}996\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$5.3 - 0.030\,S^{1/2}$	13413	$23{,}599\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$8.1 - 0.083\,S$	65	$11{,}420\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$9.2 - 0.389\,S^{1/2}$	187	$6.1 - 0.165\,S^{1/2}$	715	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	4.8	10.7	$6.1 - 0.119\,S$	34	$2{,}417\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	4.8	10.7	$6.1 - 0.119\,S$	25.8	$79\,/S$
flat elements supported on both edges	B.5.4.2	b/t	4.8	33.6	$6.1 - 0.038\,S$	81	$247\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	4.8	22.8	$5.3 - 0.019\,S$	185	$60{,}414\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	4.8	59.0	$6.1 - 0.165\,S^{1/2}$	715	$3{,}776\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	4.8	53.7	$6.1 - 0.024\,S$	129	$395\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	6.3	76.9	$8.1 - 0.023\,S$	173	$699\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	6.3	14.3	$8.1 - 0.127\,S$	43	$4{,}932\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	6.3	172.3	$8.1 - 0.010\,S$	387	$1{,}567\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	6.3	50.0	$8.1 - 0.036\,S$	112	$455\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	2.9	56.7	$3.7 - 0.014\,S$	177	$38{,}665\,/S^2$

Table 2-22W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

6082 – T6, T6511 **Extrusions**

F_{ty} = 16 k/in^2
F_{cy} = 16 k/in^2
F_{tu} = 28 k/in^2
E = 10,100 k/in^2
k_t = 1

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	14.4
axial tension stress on gross area	D.2a	9.7

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	9.7	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	12.6	12.6 see also F.4.2
round tubes	F.6.1	11.3	11.3 see also F.6.2
rods	F.7	12.6	12.6

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	28.7
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	19.1

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$9.3 - 0.048\,S$	129	$51{,}352/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$10.9 - 0.047\,S$	155	$86{,}996/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$10.9 - 0.090\,S^{1/2}$	6486	$23{,}599/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$17.2 - 0.256\,S$	45	$11{,}420/S^2$
round tubes local buckling	F.6.2	R_b/t	$18.9 - 1.021\,S^{1/2}$	115	$12.6 - 0.434\,S^{1/2}$	366	$3{,}776/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	9.7	8.8	$12.9 - 0.363\,S$	24	$2{,}417/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	9.7	8.8	$12.9 - 0.363\,S$	17.8	$115/S$
flat elements supported on both edges	B.5.4.2	b/t	9.7	27.7	$12.9 - 0.116\,S$	56	$358/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	9.7	21.7	$10.9 - 0.057\,S$	129	$60{,}414/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	9.7	45.2	$12.6 - 0.434\,S^{1/2}$	366	$3{,}776/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	9.7	44.2	$12.9 - 0.073\,S$	89	$573/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	12.6	62.9	$17.2 - 0.072\,S$	119	$1{,}017/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	12.6	11.7	$17.2 - 0.389\,S$	29	$4{,}932/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	12.6	141.1	$17.2 - 0.032\,S$	266	$2{,}280/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	12.6	40.9	$17.2 - 0.111\,S$	77	$661/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	5.8	46.6	$7.8 - 0.043\,S$	122	$38{,}665/S^2$

Table 2-23W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

6351 – T6 **Extrusions (See note)**

F_{ty} = 11 k/in² E = 10,100 k/in²
F_{cy} = 11 k/in² k_t = 1
F_{tu} = 24 k/in²

Allowable Stresses F/Ω (k/in²)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	12.3
axial tension stress on gross area	D.2a	6.7

Flexure		**Tension**	**Compression**
elements in uniform stress	F.8.1.1	6.7	see B.5.4.1 thru B.5.4.5 and E.4.2
elements in flexure	F.8.1.2, F.4.1	8.7	8.7 see also F.4.2
round tubes	F.6.1	7.8	7.8 see also F.6.2
rods	F.7	8.7	8.7

Note:
Welded with 4043, 5554, or 5654 filler and > 0.375" thick
For other cases, use Table 2-19W

Bearing		
bolts or rivets on holes	J.3.7a, J.4.7	24.6
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	16.4

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$6.3 - 0.027\ S$	157	$51{,}352\ /S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$7.4 - 0.026\ S$	188	$86{,}996\ /S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$7.4 - 0.050\ S^{1/2}$	9618	$23{,}599\ /S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$11.4 - 0.139\ S$	55	$11{,}420\ /S^2$
round tubes local buckling	F.6.2	R_b/t	$12.8 - 0.606\ S^{1/2}$	150	$8.5 - 0.257\ S^{1/2}$	524	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	6.7	9.8	$8.6 - 0.198\ S$	29	$2{,}417\ /S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	6.7	9.8	$8.6 - 0.198\ S$	21.8	$94\ /S$
flat elements supported on both edges	B.5.4.2	b/t	6.7	30.8	$8.6 - 0.063\ S$	68	$293\ /S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	6.7	22.3	$7.4 - 0.031\ S$	157	$60{,}414\ /S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	6.7	52.2	$8.5 - 0.257\ S^{1/2}$	524	$3{,}776\ /[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	6.7	49.2	$8.6 - 0.040\ S$	109	$468\ /S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	8.7	70.3	$11.4 - 0.039\ S$	145	$830\ /S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	8.7	13.0	$11.4 - 0.212\ S$	36	$4{,}932\ /S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	8.7	157.5	$11.4 - 0.018\ S$	326	$1{,}861\ /S$
flat elements—alternate method	B.5.5.4	λ_{eq}	8.7	45.7	$11.4 - 0.060\ S$	94	$540\ /S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	4.0	51.9	$5.2 - 0.023\ S$	149	$38{,}665\ /S^2$

Table 2-24W
ALLOWABLE STRESSES FOR BUILDING-TYPE STRUCTURES (WELDED)

7005 – T53 **Extrusions**

$F_{ty} = 24$ k/in^2 $E = 10{,}500$ k/in^2
$F_{cy} = 24$ k/in^2 $k_t = 1$
$F_{tu} = 40$ k/in^2

Allowable Stresses F/Ω (k/in^2)	**Section**	**F/Ω**
Axial Tension		
axial tension stress on net effective area	D.2b	20.5
axial tension stress on gross area	D.2a	14.5

Flexure		**Tension**	**Compression**	
elements in uniform stress	F.8.1.1	14.5	see B.5.4.1 thru B.5.4.5 and E.4.2	
elements in flexure	F.8.1.2, F.4.1	18.9	18.9	see also F.4.2
round tubes	F.6.1	17.0	17.0	see also F.6.2
rods	F.7	18.9	18.9	
Bearing				
bolts or rivets on holes	J.3.7a, J.4.7	41.0		
bolts on slots, pins on holes, flat surfaces	J.3.7b, J.7	27.3		

Axial Compression		**Slenderness S**	**F/Ω for $S \le S_1$**	**S_1**	**F/Ω for $S_1 < S < S_2$**	**S_2**	**F/Ω for $S \ge S_2$**
all shapes member buckling	E.3	kL/r			$14.3 - 0.090\,S$	106	$53{,}386\,/S^2$
Flexural Compression							
open shapes lateral-torsional buckling	F.2.1	$L_b/(r_{ye}C_b^{1/2})$			$16.8 - 0.088\,S$	127	$90{,}441\,/S^2$
closed shapes lateral-torsional buckling	F.3.1	$2L_bS_c/(C_b(I_yJ)^{1/2})$			$16.8 - 0.169\,S^{1/2}$	4384	$24{,}534\,/S$
rectangular bars lateral-torsional buckling	F.4.2	$(d/t)(L_b/(C_bd))^{1/2}$			$26.7 - 0.488\,S$	37	$11{,}873\,/S^2$
round tubes local buckling	F.6.2	R_b/t	$28.9 - 1.775\,S^{1/2}$	89	$19.3 - 0.755\,S^{1/2}$	257	$3{,}925\,/[S(1+S^{1/2}/35)^2]$
Elements—Uniform Compression							
flat elements supported on one edge in columns whose buckling axis is not an axis of symmetry	B.5.4.1	b/t	14.5	8.0	$20.1 - 0.690\,S$	19	$2{,}512\,/S^2$
flat elements supported on one edge in all other columns and all beams	B.5.4.1	b/t	14.5	8.0	$20.1 - 0.690\,S$	14.5	$146\,/S$
flat elements supported on both edges	B.5.4.2	b/t	14.5	25.0	$20.1 - 0.221\,S$	45	$456\,/S$
flat elements supported on both edges and with an intermediate stiffener	B.5.4.4	λ_s	14.5	21.3	$16.8 - 0.106\,S$	106	$62{,}807\,/S^2$
curved elements supported on both edges	B.5.4.5	R_b/t	14.5	39.5	$19.3 - 0.755\,S^{1/2}$	257	$3{,}925\,/[S(1+S^{1/2}/35)^2]$
flat elements—alternate method	B.5.4.6	λ_{eq}	14.5	40.0	$20.1 - 0.138\,S$	73	$729\,/S$
Elements—Flexural Compression							
flat elements supported on both edges	B.5.5.1	b/t	18.9	56.7	$26.7 - 0.138\,S$	97	$1{,}294\,/S$
flat elements supported on tension edge, compression edge free	B.5.5.2	b/t	18.9	10.5	$26.7 - 0.742\,S$	24	$5{,}127\,/S^2$
flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	b/t	18.9	127.1	$26.7 - 0.062\,S$	217	$2{,}901\,/S$
flat elements—alternate method	B.5.5.4	λ_{eq}	18.9	36.8	$26.7 - 0.212\,S$	63	$841\,/S$
Elements—Shear							
flat elements supported on both edges	G.2	b/t	8.7	42.1	$12.1 - 0.081\,S$	100	$40{,}196\,/S^2$

Table 3-1

RECOMMENDED MINIMUM BEND RADII FOR 90° COLD BENDS, SHEET AND PLATE ① ② ③ ④ ⑤

Alloy	Temper	RADII FOR VARIOUS THICKNESSES EXPRESSED IN TERMS OF THICKNESS "t"							
		1⁄64 in.	1⁄32 in.	1⁄16 in.	1⁄8 in.	3⁄16 in.	1⁄4 in.	3⁄8 in.	1⁄2 in.
1100	O	0	0	0	0	½t	1t	1t	1½t
	H12	0	0	0	½t	1t	1t	1½t	2t
	H14	0	0	0	1t	1t	1½t	2t	2½t
	H16	0	½t	1t	1½t	1½t	2½t	3t	4t
	H18	1t	1t	1½t	2½t	3t	3½t	4t	4½t
2014	O	0	0	0	½t	1t	1t	2½t	4t
	T3	1½t	2½t	3t	4t	5t	5t	6t	7t
	T4	1½t	2½t	3t	4t	5t	5t	6t	7t
	T6	3t	4t	4t	5t	6t	8t	8½t	9½t
2024	O	0	0	0	½t	1t	1t	2½t	4t
	T3	2½t	3t	4t	5t	5t	6t	7t	7½t
	T361⑥	3t	4t	5t	6t	6t	8t	8½t	9½t
	T4	2½t	3t	4t	5t	5t	6t	7t	7½t
	T81	4½t	5½t	6t	7½t	8t	9t	10t	10½t
	T861⑥	5t	6t	7t	8½t	9½t	10t	11½t	11½t
2036	T4	. .	1t	1t	. .	. .	. .	. .	. .
3003	O	0	0	0	0	½t	1t	1t	1½t
	H12	0	0	0	½t	1t	1t	1½t	2t
	H14	0	0	0	1t	1t	1½t	2t	2½t
	H16	½t	1t	1t	1½t	2½t	3t	3½t	4t
	H18	1t	1½t	2t	2½t	3½t	4½t	5½t	6½t
3004	O	0	0	0	½t	1t	1t	1t	1½t
	H32	0	0	½t	1t	1t	1½t	1½t	2t
	H34	0	1t	1t	1½t	1½t	2½t	2½t	3t
	H36	1t	1t	1½t	2½t	3t	3½t	4t	4½t
	H38	1t	1½t	2½t	3t	4t	5t	5½t	6½t
3105	H25	½t	½t	½t	. .	. .	. .	. .	. .
5005	O	0	0	0	0	½t	1t	1t	1½t
	H12	0	0	0	½t	1t	1t	1½t	2t
	H14	0	0	0	1t	1½t	1½t	2t	2½t
	H16	½t	1t	1t	1½t	2½t	3t	3½t	4t
	H18	1t	1½t	2t	2½t	3½t	4½t	5½t	6½t
	H32	0	0	0	½t	1t	1t	1½t	2t
	H34	0	0	0	1t	1½t	1½t	2t	2½t
	H36	½t	1t	1t	1½t	2½t	3t	3½t	4t
	H38	1t	1½t	2t	2½t	3½t	4½t	5½t	6½t
5050	O	0	0	0	½t	1t	1t	1½t	1½t
	H32	0	0	0	1t	1t	1½t	. .	. .
	H34	0	0	1t	1½t	1½t	2t	. .	. .
	H36	1t	1t	1½t	2t	2½t	3t	. .	. .
	H38	1t	1½t	2½t	3t	4t	5t	. .	. .
5052	O	0	0	0	½t	1t	1t	1½t	1½t
	H32	0	0	1t	1½t	1½t	1½t	1½t	2t
	H34	0	1t	1½t	2t	2t	2½t	2½t	3t
	H36	1t	1t	1½t	2½t	3t	3½t	4t	4½t
	H38	1t	1½t	2½t	3t	4t	5t	5½t	6½t
5083	O	. .	. .	½t	1t	1t	1t	1½t	1½t
	H321	. .	. .	1t	1½t	1½t	1½t	2t	2½t
5086	O	0	0	½t	1t	1t	1t	1½t	1½t
	H32	0	½t	1t	1½t	1½t	2t	2½t	3t
	H34	½t	1t	1½t	2t	2½t	3t	3½t	4t
	H36	1½t	2t	2½t	3t	3½t	4t	4½t	5t

Table 3-1
RECOMMENDED MINIMUM BEND RADII FOR 90º COLD BENDS, SHEET AND PLATE ①②③④⑤ (Continued)

Alloy	Temper	RADII FOR VARIOUS THICKNESSES EXPRESSED IN TERMS OF THICKNESS "t"							
		1/64 in.	1/32 in.	1/16 in.	1/8 in.	3/16 in.	1/4 in.	3/8 in.	1/2 in.
5154	O	0	0	½t	1t	1t	1t	1½t	1½t
	H32	0	½t	1t	1½t	1½t	2t	2½t	3½t
	H34	½t	1t	1½t	2t	2½t	3t	3½t	4t
	H36	1t	1½t	2t	3t	3½t	4t	4½t	5t
	H38	1½t	2½t	3t	4t	5t	5t	6½t	6½t
5252	H25	0	0	1t	2t	. .	. .	. .	. .
	H28	1t	1½t	2½t	3t	. .	. .	. .	. .
5254	O	0	0	½t	1t	1t	1t	1½t	1½t
	H32	0	½t	1t	1½t	1½t	2t	2½t	3½t
	H34	½t	1t	1½t	2t	2½t	3t	3½t	4t
	H36	1t	1½t	2t	3t	3½t	4t	4½t	5t
	H38	1½t	2½t	3t	4t	5t	5t	6½t	6½t
5454	O	0	½t	1t	1t	1t	1½t	1½t	2t
	H32	½t	½t	1t	2t	2t	2½t	3t	4t
	H34	½t	1t	1½t	2t	2½t	3t	3½t	4t
5456	O	. .	. .	1t	1t	1½t	1½t	2t	2t
	H321	. .	. .	. .	2t	2t	2½t	3t	3½t
5457	O	0	0	0	. .	. .	. .	. .	. .
5652	O	0	0	0	½t	1t	1t	1½t	1½t
	H32	0	0	1t	1½t	1½t	1½t	1½t	2t
	H34	0	1t	1½t	2t	2t	2½t	2½t	3t
	H36	1t	1t	1½t	2½t	3t	3½t	4t	4½t
	H38	1t	1½t	2½t	3t	4t	5t	5½t	6½t
5657	H25	0	0	0	1t	. .	. .	. .	. .
	H28	1t	1½t	2½t	3t	. .	. .	. .	. .
6061	O	0	0	0	1t	1t	1t	1½t	2t
	T4	0	0	1t	1½t	2½t	3t	3½t	4t
	T6	1t	1t	1½t	2½t	3t	3½t	4½t	5t
7050	T7	. .	. .	. .	. .	. .	8t	9t	9½t
7072	O	0	0	. .	. .	. .	. .	. .	. .
	H14	0	0	. .	. .	. .	. .	. .	. .
	H18	1t	1t	. .	. .	. .	. .	. .	. .
7075	O	0	0	1t	1t	1½t	2½t	3½t	4t
	T6	3t	4t	5t	6t	6t	8t	9t	9½t
7178	O	0	0	1t	1½t	1½t	2½t	3½t	4t
	T6	3t	4t	5t	6t	6t	8t	9t	9½t

① The radii listed are the minimum recommended for bending sheets and plates without fracturing in a standard press brake with air bend dies. Other types of bending operations may require larger radii or permit smaller radii. The minimum permissible radii will also vary with the design and condition of the tooling.

② Alclad sheet in the heat-treatable alloys can be bent over slightly smaller radii than the corresponding tempers of the bare alloy.

③ Heat-treatable alloys can be formed over appreciably smaller radii immediately after solution heat treatment.

④ The H112 temper (applicable to non-heat treatable alloys) is supplied in the as-fabricated condition without special property control but usually can be formed over radii applicable to the H14 (or H34) temper or smaller.

⑤ The reference test method is ASTM E290.

⑥ Tempers T361 and T861 formerly designated T36 and T86, respectively.

Table 3-2
RECOMMENDED MINIMUM INSIDE RADII FOR 180° COLD BENDS, WIRE AND ROD*

Alloy and Temper	Approximate diameter, in. 0.062 (1/16)	0.125 (⅛)	0.250 (¼)	0.500 (½)
1100-O	. . .	. . .	¼ to ½D	¼ to ½D
1350-H19	0 to 1D	0 to 1D	0 to 1D	0 to 1D
2011-T3	. . .	. . .	½D	½D
2011-T8	. . .	. . .	½ to 1D	1 to 1½D
2017-T4, T451	. . .	. . .	½ to 1D	1 to 1½D
2024-T4	. . .	. . .	1D	. . .
2024-T351	. . .	. . .	. . .	2 to 2½D
5050-H38	0 to 1D	0 to 1D	1 to 2D	2 to 4D
5052-H38	0 to 1D	1 to 2D	2 to 4D	3 to 5D
5056-H34	0 to 1D	1 to 2D	2 to 4D	3 to 5D
5056-H38	0 to 1D	1 to 2D	2 to 4D	4 to 6D
6061-T6, T651	0 to 1D	0 to 1D	½ to 1½D	½ to 1½D
6061-T913	0 to 1D	1 to 2D	2 to 4D	4 to 6D
6262-T9	. . .	. . .	1 to 1½D	1 to 1½D
7075-T6, T651	½ to 1½D	1 to 2D	1½ to 2½D	2 to 3D

*Minimum permissible radius over which metal may be bent varies with nature of forming operation, type of forming equipment, design and condition of tools. Minimum working radius for a given material or hardest alloy and temper for a given radius can be ascertained only by actual trial under contemplated conditions of fabrication.

Table 3-3
SHEET THICKNESS FOR 180° COLD BENDING (METAL TO METAL)*

Alloy and Temper	Maximum Metal Thickness In.
1100-0	.125
-H14	.063
2014-0	.063
2024-0	.063
3003-0	.125
-H14	.063
3004-0	.063
-H32	.031
-H34	.016
5005-0	.125
-H12	.063
-H32	.063
-H14	.031
-H34	.031

Alloy and Temper	Maximum Metal Thickness In.
5050-0	.063
-H34	.031
5052-0	.063
-H32	.031
-H34	.016
5086-0	.031
5154-H32	.016
6061-0	.063
-T4	.031
7075-0	.031

*Minimum permissible radius over which metal may be bent varies with nature of forming operation, type of forming equipment, design and condition of tools. Minimum working radius for a given material or hardest alloy and temper for a given radius can be ascertained only by actual trial under contemplated conditions of fabrication.

Table 3-4
DEVELOPED LENGTH OF MATERIAL FOR 90° BENDS

Material Thickness in.	Inside Radius of Bend (in.)																	
	Sharp Bend	1/64	1/32	3/64	1/16	5/64	3/32	7/64	1/8	5/32	3/16	7/32	1/4	5/16	3/8	7/16	1/2	5/8
.016	.008	.033	.061	.086	.111	.135	.160	.184	.209	.258	.307	.356	.406	.503	.602	.700	.798	.994
.020	.011	.035	.063	.089	.114	.138	.163	.187	.212	.261	.310	.359	.408	.507	.605	.703	.801	.998
.025	.013	.038	.064	.092	.118	.142	.167	.191	.216	.265	.314	.363	.412	.511	.609	.707	.805	1.001
.032	.017	.041	.066	.094	.123	.148	.173	.197	.222	.271	.320	.369	.418	.516	.614	.712	.811	1.007
.040	.021	.045	.070	.097	.126	.153	.179	.203	.228	.277	.326	.375	.424	.522	.621	.719	.817	1.013
.051	.027	.051	.076	.100	.129	.155	.184	.212	.236	.285	.334	.383	.433	.531	.629	.727	.825	1.022
.057	.030	.054	.079	.103	.130	.156	.185	.214	.241	.290	.339	.388	.438	.536	.634	.732	.830	1.027
.063	.033	.057	.082	.106	.131	.158	.186	.216	.245	.294	.344	.393	.442	.540	.638	.736	.834	1.031
.072	.038	.062	.087	.111	.135	.161	.189	.220	.248	.302	.351	.400	.449	.547	.646	.744	.842	1.038
.081	.042	.067	.091	.116	.140	.165	.191	.224	.250	.307	.358	.407	.456	.554	.653	.751	.849	1.045
.091	.047	.072	.096	.121	.146	.170	.194	.227	.252	.312	.366	.415	.464	.562	.660	.758	.857	1.053
.102	.053	.078	.102	.127	.151	.176	.200	.230	.258	.316	.370	.424	.473	.571	.669	.767	.865	1.062
.109	.057	.082	.106	.131	.155	.180	.204	.232	.261	.319	.371	.429	.478	.577	.675	.773	.871	1.067
.125	.065	.090	.114	.139	.164	.188	.213	.237	.267	.324	.373	.434	.491	.589	.687	.785	.884	1.080
.156	.082	.106	.131	.155	.180	.204	.229	.253	.278	.332	.384	.444	.500	.614	.712	.810	.908	1.104
.188	.098	.123	.147	.172	.196	.221	.245	.270	.295	.344	.394	.454	.510	.624	.736	.834	.933	1.129
.250	.131	.155	.180	.204	.229	.254	.278	.303	.327	.376	.425	.474	.529	.643	.756	.869	.982	1.178
.313	.164	.188	.213	.237	.262	.286	.311	.335	.360	.409	.458	.507	.556	.662	.776	.889	1.002	1.227
.375	.196	.221	.245	.270	.295	.319	.344	.386	.393	.442	.491	.540	.589	.687	.797	.909	1.022	1.247
.500	.262	.286	.311	.335	.360	.384	.409	.433	.458	.507	.556	.605	.654	.753	.851	.949	1.061	1.285
.625	.328	.352	.377	.401	.426	.450	.475	.499	.524	.573	.622	.671	.720	.818	.916	1.014	1.113	1.323
.750	.393	.417	.442	.466	.491	.513	.540	.564	.589	.638	.687	.736	.785	.884	.982	1.080	1.178	1.374
.875	.458	.483	.507	.532	.556	.581	.605	.630	.654	.703	.753	.802	.851	.949	1.047	1.145	1.243	1.440
1.000	.524	.548	.573	.597	.622	.646	.671	.695	.720	.769	.818	.867	.916	1.014	1.113	1.211	1.309	1.505

Table 3-4
DEVELOPED LENGTH OF MATERIAL FOR 90° BENDS (Continued)

Material Thickness in.	Inside Radius of Bend (in.)																	
	¾	⅞	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½
.016	1.191	1.387	1.583	1.976	2.368	2.761	3.154	3.547	3.940	4.332	4.725	5.118	5.510	5.903	6.298	7.081	7.867	8.652
.020	1.194	1.390	1.587	1.979	2.372	2.765	3.157	3.550	3.943	4.335	4.728	5.121	5.514	5.905	6.299	7.084	7.870	8.655
.025	1.198	1.394	1.590	1.983	2.376	2.769	3.161	3.554	3.947	4.339	4.732	5.125	5.517	5.910	6.303	7.088	7.874	8.659
.032	1.203	1.400	1.596	1.989	2.381	2.774	3.167	3.559	3.952	4.345	4.738	5.130	5.523	5.916	6.308	7.094	7.879	8.665
.040	1.210	1.406	1.602	1.995	2.388	2.780	3.173	3.566	3.958	4.351	4.744	5.137	5.529	5.922	6.315	7.100	7.885	8.671
.051	1.218	1.414	1.611	2.003	2.396	2.789	3.181	3.574	3.967	4.360	4.752	5.145	5.538	5.930	6.323	7.109	7.894	8.679
.057	1.223	1.419	1.616	2.008	2.401	2.794	3.186	3.579	3.972	4.365	4.757	5.150	5.543	5.935	6.328	7.113	7.899	8.684
.063	1.227	1.423	1.620	2.013	2.405	2.798	3.191	3.583	3.977	4.369	4.761	5.154	5.547	5.940	6.332	7.118	7.903	8.688
.072	1.235	1.431	1.627	2.020	2.413	2.805	3.198	3.591	3.984	4.376	4.769	5.162	5.554	5.947	6.340	7.125	7.911	8.696
.081	1.242	1.438	1.634	2.027	2.420	2.812	3.205	3.598	3.990	4.383	4.776	5.169	5.561	5.954	6.347	7.132	7.917	8.703
.091	1.249	1.446	1.642	2.035	2.427	2.820	3.213	3.605	3.998	4.391	4.784	5.176	5.569	5.962	6.354	7.140	7.925	8.711
.102	1.258	1.454	1.651	2.043	2.436	2.829	3.222	3.614	4.007	4.400	4.792	5.185	5.578	5.971	6.363	7.149	7.934	8.719
.109	1.264	1.461	1.656	2.049	2.442	2.835	3.227	3.620	4.013	4.405	4.798	5.191	5.583	5.976	6.369	7.154	7.940	8.725
.125	1.301	1.473	1.669	2.062	2.454	2.847	3.240	3.632	4.025	4.418	4.811	5.203	5.596	5.989	6.381	7.167	7.952	8.738
.156	1.301	1.497	1.693	2.086	2.479	2.872	3.264	3.657	4.050	4.442	4.835	5.228	5.620	6.013	6.406	7.191	7.977	8.762
.188	1.325	1.522	1.718	2.111	2.503	2.896	3.289	3.681	4.074	4.467	4.860	5.252	5.645	6.038	6.430	7.216	8.001	8.787
.250	1.374	1.571	1.767	2.160	2.553	2.945	3.338	3.731	4.123	4.516	4.909	5.301	5.694	6.087	6.480	7.265	8.050	8.836
.313	1.423	1.620	1.816	2.209	2.602	2.994	3.387	3.780	4.172	4.565	4.958	5.350	5.743	6.136	6.529	7.314	8.099	8.885
.375	1.473	1.669	1.865	2.258	2.651	3.043	3.436	3.829	4.222	4.614	5.007	5.400	5.792	6.185	6.578	7.363	8.149	8.934
.500	1.511	1.737	1.964	2.356	2.749	3.142	3.584	3.027	4.320	4.712	5.105	5.498	5.891	6.283	6.676	7.461	8.247	9.032
.625	1.548	1.774	2.001	2.454	2.847	3.240	3.632	4.025	4.418	4.811	5.203	5.596	5.989	6.381	6.774	7.560	8.345	9.130
.750	1.585	1.812	2.038	2.491	2.915	3.338	3.731	4.123	4.516	4.909	5.301	5.694	6.087	6.480	6.872	7.658	8.443	9.228
.875	1.636	1.850	2.075	2.529	2.983	3.436	3.829	4.222	4.614	5.007	5.400	5.792	6.185	6.578	6.970	7.756	8.541	9.327
1.000	1.702	1.898	2.112	2.566	3.021	3.474	3.927	4.320	4.712	5.105	5.498	5.891	6.283	6.676	7.069	7.854	8.639	9.426

*Developed Length = (Length Before Bending) − (Sum of the Flat Lengths)

Table 4-1
ALLOWABLE UNIFORM BEAM LOADS*
Aluminum Association Standard Channels, 6061-T6

Depth d in.	Weight lb/ft	Span (ft) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
2	.577	3.67 0.03 3.67	1.84 0.11 1.62	1.22 0.26 0.94																		
2	1.07	6.97 0.03 6.97	3.46 0.11 3.45	2.32 0.26 2.13																		
3	1.14	9.36 0.01 9.36	5.95 0.08 5.75	3.97 0.17 3.40	2.98 0.30 2.28	2.38 0.47 1.44																
3	1.60	12.24 0.01 12.24	8.30 0.08 8.30	5.53 0.17 5.13	4.15 0.30 3.55	3.32 0.47 2.64																
4	1.74	14.40 0.01 14.40	12.35 0.06 12.35	8.23 0.13 7.66	6.17 0.23 5.21	4.94 0.36 3.79	4.12 0.51 2.57	3.53 0.70 1.80														
4	2.33	18.24 0.01 18.24	16.47 0.06 16.47	10.98 0.13 10.69	8.23 0.23 7.42	6.59 0.36 5.52	5.49 0.51 4.30	4.70 0.70 3.34														
5	2.21		18.00 0.04 18.00	13.30 0.10 12.71	9.97 0.18 8.67	7.98 0.28 6.32	6.65 0.41 4.52	5.70 0.56 3.10	4.99 0.73 2.26													
5	3.09		22.80 0.04 22.80	18.79 0.10 18.79	14.09 0.18 13.24	11.27 0.28 9.88	9.39 0.41 7.70	8.05 0.56 6.19	7.05 0.73 4.78													
6	2.83			20.18 0.09 19.84	15.14 0.15 13.65	12.11 0.24 10.01	10.09 0.34 7.65	8.65 0.47 5.33	7.57 0.61 3.83	6.73 0.77 2.89	6.05 0.95 2.25											
6	4.03			29.60 0.09 29.60	22.20 0.15 21.76	17.76 0.24 16.35	14.80 0.34 12.81	12.68 0.47 10.34	11.10 0.61 8.53	9.87 0.77 6.79	8.88 0.95 5.28											
7	3.21			26.64 0.07 26.64	19.98 0.13 18.49	15.99 0.20 13.61	13.32 0.29 10.41	11.42 0.40 7.60	9.99 0.52 5.37	8.88 0.66 3.99	7.99 0.81 3.07	7.27 0.99 2.44	6.66 1.17 1.98									
7	4.72				30.56 0.13 30.41	24.45 0.20 22.90	20.37 0.29 17.97	17.46 0.40 14.51	15.28 0.52 11.97	13.58 0.66 9.84	12.22 0.81 7.59	11.11 0.99 6.03	10.19 1.17 4.91									
8	4.15				29.61 0.11 28.17	23.69 0.18 20.90	19.74 0.26 16.13	16.92 0.35 12.79	14.80 0.46 9.24	13.16 0.58 6.83	11.84 0.71 5.25	10.77 0.86 4.15	9.87 1.03 3.36	9.11 1.20 2.78	8.46 1.40 2.34							
8	5.79				41.70 0.11 41.71	33.36 0.18 31.88	27.80 0.26 25.10	23.83 0.35 20.33	20.85 0.46 16.82	18.54 0.58 14.13	16.68 0.72 11.29	15.17 0.86 8.92	13.90 1.03 7.22	12.83 1.20 5.96	11.92 1.40 5.01							
9	4.98					30.63 0.16 27.81	25.52 0.23 21.58	21.88 0.31 17.20	19.14 0.41 13.38	17.02 0.51 9.81	15.31 0.63 7.48	13.92 0.77 5.88	12.76 0.91 4.73	11.78 1.07 3.89	10.94 1.24 3.26	10.21 1.42 2.76						
9	6.97					44.08 0.16 42.91	36.73 0.23 33.89	31.49 0.31 27.54	27.55 0.41 22.84	24.49 0.51 19.25	22.04 0.63 16.43	20.04 0.77 12.86	18.37 0.91 10.37	16.95 1.07 8.53	15.74 1.24 7.14	14.69 1.42 6.07						
10	6.14						35.13 0.21 30.64	30.11 0.28 24.57	26.35 0.36 20.09	23.42 0.46 15.32	21.08 0.57 11.65	19.16 0.69 9.13	17.56 0.82 7.34	16.21 0.96 6.02	15.06 1.12 5.03	14.05 1.28 4.26	13.17 1.46 3.66	12.40 1.65 3.18				
10	8.36						49.04 0.21 46.11	42.04 0.28 37.58	36.78 0.36 31.27	32.69 0.46 26.44	29.42 0.57 22.63	26.75 0.69 18.85	24.52 0.82 15.16	22.63 0.96 12.45	21.02 1.12 10.40	19.62 1.28 8.82	18.39 1.46 7.58	17.31 1.65 6.58				
12	8.27							48.19 0.23 41.56	42.16 0.30 34.27	37.48 0.38 28.67	33.73 0.47 22.67	30.66 0.57 17.64	28.11 0.68 14.06	25.95 0.80 11.46	24.09 0.93 9.51	22.49 1.07 8.01	21.08 1.22 6.84	19.84 1.37 5.91	18.74 1.54 5.15	17.75 1.71 4.53	16.87 1.90 4.02	16.06 2.09 3.59
12	11.8							72.29 0.23 68.19	63.25 0.30 57.18	56.23 0.38 48.71	50.60 0.47 42.02	46.00 0.57 36.62	42.17 0.68 32.18	38.93 0.80 27.42	36.15 0.93 22.79	33.74 1.07 19.23	31.63 1.22 16.44	29.77 1.37 14.21	28.11 1.54 12.41	26.63 1.71 10.93	25.30 1.90 9.71	24.10 2.09 8.68

*Total uniformly distributed load *W* applied at the beam's neutral axis on a simply supported single span braced against twisting, calculated using the section properties listed in Part V, Table 4, the allowable stresses for building-type structures given in Part VI, Table 2-19, and r_{ye} from Part I, Section F.2.2.1.

EXAMPLE

Span in Ft.
3
2″ [a. 1.22
b. 0.26
c. 0.94

a = W, Kips } Laterally
b = defl. in In. } supported
c = W, Kips Not laterally supported

Table 4-2
ALLOWABLE UNIFORM BEAM LOADS*
Aluminum Association Standard I-Beams, 6061-T6

Depth d in.	Weight lb/ft	SPAN (FT)																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
3	1.64	9.36 0.01 9.36	9.36 0.08 9.36	6.29 0.17 5.79	4.72 0.30 3.96	3.77 0.47 2.91																
3	2.03	10.80 0.01 10.80	10.80 0.07 10.80	7.64 0.17 7.27	5.73 0.30 5.07	4.59 0.47 3.79																
4	2.31	14.40 0.01 14.40	14.40 0.05 14.40	11.86 0.13 11.36	8.90 0.23 7.80	7.12 0.36 5.73	5.93 0.51 4.35	5.08 0.70 3.03														
4	2.79	16.32 0.01 16.32	16.32 0.04 16.32	14.19 0.13 13.79	10.64 0.23 9.58	8.51 0.36 7.13	7.09 0.51 5.56	6.08 0.70 4.32														
5	3.70		22.80 0.03 22.80	22.80 0.10 22.80	17.67 0.18 16.37	14.14 0.28 12.20	11.78 0.41 9.49	10.10 0.56 7.62	8.84 0.73 5.71													
6	4.03			27.36 0.08 27.36	23.21 0.15 21.92	18.57 0.24 16.29	15.47 0.34 12.61	13.26 0.47 10.05	11.61 0.61 7.40	10.32 0.77 5.55	9.28 0.95 4.32											
6	4.69			30.24 0.07 30.24	26.92 0.15 25.74	21.53 0.24 19.26	17.94 0.34 15.03	15.38 0.47 12.09	13.46 0.61 9.74	11.96 0.77 7.37	10.77 0.95 5.77											
7	5.80				38.64 0.13 38.05	31.03 0.20 28.58	25.86 0.29 22.38	22.17 0.40 18.04	19.40 0.52 14.86	17.24 0.66 11.69	15.52 0.81 9.07	14.11 0.99 7.24	12.93 1.17 5.92									
8	6.18				44.16 0.11 44.16	37.80 0.18 35.49	31.50 0.26 27.79	27.00 0.35 22.38	23.62 0.46 18.38	21.00 0.58 14.72	18.90 0.71 11.24	17.18 0.86 8.85	15.75 1.03 7.14	14.54 1.20 5.89	13.50 1.40 4.93							
8	7.02				48.00 0.10 48.00	42.91 0.18 40.70	35.76 0.25 32.01	30.65 0.35 25.90	26.82 0.46 21.41	23.84 0.58 17.98	21.46 0.71 14.09	19.51 0.86 11.17	17.88 1.03 9.06	16.51 1.20 7.50	15.33 1.40 6.32							
9	8.36					57.43 0.16 55.72	47.86 0.23 43.99	41.02 0.31 35.72	35.89 0.41 29.60	31.91 0.51 24.93	28.72 0.63 20.91	26.10 0.77 16.46	23.93 0.91 13.27	22.09 1.07 10.93	20.51 1.24 9.15	19.14 1.42 7.78						
10	8.65						55.78 0.21 52.20	47.81 0.28 42.43	41.83 0.36 35.18	37.18 0.46 29.62	33.47 0.57 25.23	30.42 0.69 19.99	27.89 0.82 15.96	25.74 0.96 13.02	23.90 1.12 10.81	22.31 1.28 9.12	20.92 1.46 7.79	19.69 1.65 6.73				
10	10.3						65.78 0.21 62.29	56.38 0.28 50.84	49.34 0.36 42.37	43.85 0.46 35.88	39.47 0.57 30.77	35.88 0.69 26.66	32.89 0.82 21.22	30.36 0.96 17.43	28.19 1.12 14.57	26.31 1.28 12.35	24.67 1.46 10.61	23.22 1.65 9.21				
12	11.7							77.09 0.23 72.03	67.45 0.30 60.18	59.96 0.38 51.04	53.96 0.47 43.81	49.05 0.57 37.95	44.97 0.68 32.30	41.51 0.80 26.14	38.54 0.93 21.54	35.97 1.07 18.03	33.72 1.22 15.30	31.74 1.37 13.14	29.98 1.54 11.40	28.40 1.71 9.99	26.98 1.90 8.82	25.70 2.09 7.84
12	14.3							89.28 0.22 89.28	83.74 0.30 76.25	74.44 0.38 65.03	66.99 0.47 56.15	60.90 0.57 48.99	55.83 0.68 43.10	51.53 0.80 37.62	47.85 0.93 31.25	44.66 1.07 26.36	41.87 1.22 22.53	39.41 1.37 19.47	37.22 1.54 17.00	35.26 1.71 14.97	33.50 1.90 13.29	31.90 2.09 11.87

*Total uniformly distributed load *W* applied at the beam's neutral axis on a simply supported single span braced against twisting, calculated using the section properties listed in Part V, Table 8, the allowable stresses for building-type structures given in Part VI, Table 2-19, and r_{ye} from Part I, Section F.2.2.1.

EXAMPLE

Span in Ft.
3
3″ I a. 6.29
b. 0.17
c. 5.79

a = W, Kips } Laterally
b = defl. in In. } supported
c = W, Kips Not laterally supported

Table 4-3
ALLOWABLE LOADS ON ALUMINUM TREAD PLATE
Tread Plate is sheet or plate having a raised figure pattern on one surface to provide improved traction

Allowable Loads in lb/ft^2 for 6061-T6

Plate Thickness, in.	Longer Span, Ft-In.	Shorter Span, Ft-In.						
		1′–0″	1′–6″	2′–0″	2′–6″	3′–0″	3′–6″	4′–0″
3/16	1′–0″	820						
	1′–6″	432	245					
	2′–0″	331	150	103				
	2′–6″	302	115	68	52			
	3′–0″	274	100	53	37	30		
	3′–6″	265	91	46	30	23	19	
	4′–0″	262	86	40	26	19	14	13
	Infinity	258	76	32	16	10	6	4
¼	1′–0″	1959						
	1′–6″	1022	580					
	2′–0″	778	355	245				
	2′–6″	705	274	160	124			
	3′–0″	648	230	130	88	72		
	3′–6″	633	216	109	72	55	46	
	4′–0″	619	202	94	60	45	36	30
	Infinity	605	180	76	37	23	14	9.5
⅜	1′–0″	6610						
	1′–6″	3485	1960					
	2′–0″	2650	1210	820				
	2′–6″	2400	922	550	415			
	3′–0″	2200	785	430	300	245		
	3′–6″	2140	720	360	245	187	155	
	4′–0″	2100	691	317	202	151	121	104
	Infinity	2060	605	260	130	76	49	32
½	1′–0″	15750						
	1′–6″	8250	4640					
	2′–0″	6300	2860	1960				
	2′–6″	5700	2185	1320	1000			
	3′–0″	5210	1860	1030	706	580		
	3′–6″	5080	1740	875	576	440	360	
	4′–0″	4960	1630	785	490	360	288	246
	Infinity	4890	1435	610	300	180	113	76

Loads shown in this table were calculated from formulas developed by S. Timoshenko and given on pages 156 and 157 in his "Strength of Materials," Part II, Second Edition, 1941. The bases of the formulas and therefore the calculations are:
1. The deflections are small in comparison with the thickness of the plate.
2. The plate is uniformly loaded.
3. All four edges are simply supported.

Tables are based on flat plate thickness excluding any raised pattern on the material. Loads are limited by either a maximum deflection of 1/150 of the short side length or a maximum stress of 28,000 lb/in^2.

Table 4-4
MAXIMUM SPANS (IN.)
Commercial Corrugated and V-Beam Roofing and Siding

Design Load (psf)	Number of Equal Spans					
	One		Two		Three	
	Strength	Deflection	Strength	Deflection	Strength	Deflection
Corrugated Roofing and Siding—0.024” thick						
20	79	61	79	–	88	76
25	70	57	70	–	79	70
30	64	54	64	–	72	66
35	60	51	60	–	67	63
40	56	49	56	–	63	60
45	53	47	53	–	59	58
50	50	45	50	–	56	56
Corrugated Roofing and Siding—0.032” thick						
20	92	67	92	90	102	83
25	82	63	82	–	92	77
30	75	59	75	–	84	73
35	70	56	70	–	78	69
40	65	54	65	–	73	66
45	62	52	62	–	69	64
50	58	50	58	–	65	62
V-Beam Roofing and Siding—0.032” thick, 4 7/8” Pitch						
20	128	110	128	–	144	136
25	115	102	115	–	129	127
30	105	97	105	–	118	–
35	98	92	98	–	109	–
40	92	88	92	–	102	–
45	86	85	86	–	97	–
50	82	82	82	–	92	–
55	78	–	78	–	87	–
60	75	–	75	–	84	–
V-Beam Roofing and Siding—0.040” thick, 4 7/8” Pitch						
20	150	118	150	–	167	146
25	134	110	134	–	150	136
30	123	104	123	–	137	128
35	114	99	114	–	127	122
40	107	94	107	–	119	117
45	101	91	101	–	113	112
50	96	88	96	–	107	–
55	91	85	91	–	102	–
60	87	83	87	–	98	–
V-Beam Roofing and Siding—0.050” thick, 4 7/8” Pitch						
20	171	127	171	170	191	157
25	154	118	154	–	172	146
30	141	111	141	–	158	138
35	131	106	131	–	146	131
40	122	102	122	–	137	125

Table 4-4
MAXIMUM SPANS (IN.) (Continued)
Commercial Corrugated and V-Beam Roofing and Siding

Design Load (psf)	Number of Equal Spans					
	One		Two		Three	
	Strength	Deflection	Strength	Deflection	Strength	Deflection
V-Beam Roofing and Siding—0.050” thick, 4 7/8” Pitch (continued)						
45	116	98	116	–	129	121
50	110	94	110	–	123	117
55	105	92	105	–	117	113
60	100	89	100	–	112	110
V-Beam Roofing and Siding—0.032” thick, 5 1/3” Pitch						
20	128	114	128	–	143	141
25	115	106	115	–	129	–
30	105	100	105	–	118	–
35	98	95	98	–	109	–
40	91	91	91	–	102	–
45	86	–	86	–	96	–
50	82	–	82	–	91	–
55	78	–	78	–	87	–
60	75	–	75	–	84	–
V-Beam Roofing and Siding—0.040” thick, 5 1/3” Pitch						
20	153	123	153	–	171	151
25	137	114	137	–	154	141
30	126	108	126	–	141	133
35	117	102	117	–	130	126
40	109	98	109	–	122	121
45	103	94	103	–	115	–
50	98	91	98	–	110	–
55	93	88	93	–	104	–
60	90	86	90	–	100	–
V-Beam Roofing and Siding—0.050” thick, 5 1/3” Pitch						
20	176	132	176	176	197	163
25	158	123	158	–	177	151
30	145	116	145	–	162	143
35	134	110	134	–	150	136
40	126	105	126	–	141	130
45	119	101	119	–	133	125
50	113	98	113	–	126	121
55	108	95	108	–	120	117
60	103	92	103	–	115	114

1. Maximum spans are calculated in accordance with the Specification for Aluminum Structures for allowable strength design of building-type structures.
2. Material is Alclad 3004-H151, -H261, or -H361 (which are stucco embossed tempers) or Alclad 3004-H16. Dimensions are given in Part V Table 25 and section properties are given in Part V Table 26.
3. The deflection limit is 1/60 of the span.

Table 4-5
MAXIMUM SPANS (IN.) COMMERCIAL RIBBED SIDING

Design Load (psf)	Number of Equal Spans											
	One				Two				Three			
	Strength[1]	Strength[2]	Deflection[1]	Deflection[2]	Strength[1]	Strength[2]	Deflection[1]	Deflection[2]	Strength[1]	Strength[2]	Deflection[1]	Deflection[2]
Ribbed Siding—0.032” thick, 4” Pitch												
20	98	101		85	101	98	–		113	110	106	
25	88	91		79	91	88	–		101	98	98	
30	80	83		75	83	80	–		93	90	93	
35	75	77		71	77	75	–		86	83	–	
40	70	72		68	72	70	–		80	78	–	
45	66	68		66	68	66	–		76	74	–	
50	63	64		63	64	63	–		72	70	–	
Ribbed Siding—0.040” thick, 4” Pitch												
20	118	120		92	120	118	–		134	132	113	
25	106	107		85	107	106	–		120	118	105	
30	97	98		80	98	97	–		110	108	99	
35	90	91		76	91	90	–		102	100	94	
40	84	85		73	85	84	–		95	94	90	
45	79	80		70	80	79	–		90	89	87	
50	75	76		68	76	75	–		85	84	84	
Ribbed Siding—0.032” thick, 8” Pitch												
20	62	77	74	–	77	62	–	–	78	69	–	–
25	56	69	–	–	69	56	–	–	70	62	–	–
30	51	63	–	–	63	51	–	–	64	57	–	–
35	47	59	–	–	59	47	–	–	59	53	–	–
40	44	55	–	–	55	44	–	–	55	49	–	–
45	42	52	–	–	52	42	–	–	52	47	–	–
50	40	49	–	–	49	40	–	–	49	44	–	–
Ribbed Siding—0.040” thick, 8” Pitch												
20	75	91	80	84	91	75	–	–	94	84	–	–
25	67	82	74	79	82	67	–	–	84	75	–	–
30	62	75	70	74	75	62	–	–	77	69	–	–
35	57	69	67	–	69	57	–	–	71	64	–	–
40	54	65	64	–	65	54	–	–	67	60	–	–
45	51	61	–	–	61	51	–	–	63	56	–	–
50	48	58	–	–	58	48	–	–	60	54	–	–

1. Wide flat is on loaded side; load is toward neutral axis.
2. Narrow flat is on loaded side; load is toward neutral axis.
3. Maximum spans are calculated in accordance with the Specification for Aluminum Structures for allowable strength design of building-type structures.
4. Material is Alclad 3004-H151, -H261, or -H361 (which are stucco embossed tempers) or Alclad 3004-H16. Dimensions are given in Part V Table 25 and section properties are given in Part V Table 26.
5. The deflection limit is 1/60 of the span.

Table 5-1
NOMINAL TENSILE AND SINGLE SHEAR STRENGTHS FOR 2024-T4 AND 7075-T73 MACHINE SCREWS

Nominal Size	Basic Major Diameter *D* (in.)	Threads/in. *n*		Nominal Minor Diameter (in.)	Tensile Strength (lb)		Shear Strength (lb)	
					2024-T4	7075-T73	2024-T4	7075-T73
4	0.112	40	UNC	0.0822	329	361	196	218
4	0.112	48	UNF	0.0872	370	406	221	245
5	0.125	40	UNC	0.0952	442	484	264	292
5	0.125	44	UNF	0.0979	467	512	279	309
6	0.138	32	UNC	0.1008	495	542	295	327
6	0.138	40	UNF	0.1082	570	626	340	377
8	0.164	32	UNC	0.1268	783	858	467	518
8	0.164	36	UNF	0.1309	835	915	498	552
10	0.190	24	UNC	0.1404	960	1050	573	635
10	0.190	32	UNF	0.1528	1140	1250	678	752
12	0.216	24	UNC	0.1664	1350	1480	804	891
12	0.216	28	UNF	0.1735	1470	1610	874	969
1/4	0.250	20	UNC	0.1905	1770	1940	1050	1170
1/4	0.250	28	UNF	0.2075	2100	2300	1250	1390
5/16	0.3125	18	UNC	0.2463	2950	3240	1760	1950
5/16	0.3125	24	UNF	0.2629	3360	3690	2010	2230
3/8	0.375	16	UNC	0.3006	4400	4820	2630	2910
3/8	0.375	24	UNF	0.3254	5160	5650	3080	3410

1. UNC = Unified National Course Thread Series; UNF = Unified National Fine Thread Series
2. Area at root of threads (A_r) used to compute strengths using the nominal minor diameter for external threads (Class 2A) given in ASME B1.1-1989; $A_r = (\pi/4)(D - 1.191/n)^2$
3. Obtain design strengths by dividing the strengths in this table by the appropriate safety factor or multiplying by the appropriate resistance factor (see Part I).
4. Strengths in this table were computed using:
   for 2024-T4, $F_{tu} = 62$ ksi and $F_{su} = 37$ ksi;
   for 7075-T73, $F_{tu} = 68$ ksi and $F_{su} = 41$ ksi.

Table 5-2
NOMINAL SINGLE SHEAR STRENGTHS FOR 2024-T4 AND 7075-T73 TYPE AB AND B SHEET METAL SCREWS

	Shear Strength (lb)	
Nominal Size	2024-T4	7075-T73
4	195	216
5	235	260
6	285	316
7	345	382
8	391	433
10	529	586
12	716	793
14	995	1100

1. Obtain design strengths by dividing the strengths in this table by the appropriate safety factor or multiplying by the appropriate resistance factor (see Part I).
2. Strengths in this table were computed using:
for 2024-T4, $F_{su} = 37$ ksi;
for 7075-T73, $F_{su} = 41$ ksi.

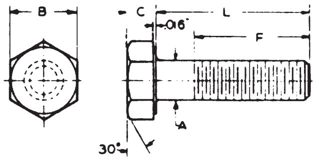
Table 5-3
NOMINAL TENSILE AND SINGLE SHEAR STRENGTHS FOR 2024-T4 AND 7075-T73 BOLTS AND CAP SCREWS

					Single Shear Strength (lb)			
			Tensile Strength (lb)		Threads in Shear Plane		No Threads in Shear Plane	
Nominal Size	Basic Major Diameter *D* (in.)	Threads/ in. *n*	2024-T4	7075-T73	2024-T4	7075-T73	2024-T4	7075-T73
10	0.190	24	960	1050	573	635	1050	1160
1/4	0.250	20	1770	1940	1050	1170	1820	2010
5/16	0.3125	18	2950	3240	1760	1950	2840	3140
3/8	0.375	16	4400	4820	2630	2910	4090	4530
1/2	0.500	13	8120	8910	4850	5370	7260	8050
5/8	0.625	11	13,000	14,300	7760	8600	11,400	12,600
3/4	0.750	10	19,400	21,300	11,600	12,800	16,300	18,100
7/8	0.875	9	26,900	29,500	16,000	17,800	22,200	24,700
1	1.000	8	35,300	38,700	21,100	23,300	29,100	32,200

1. Class 2A external threads, UNC (Unified National Course Thread Series)
2. Area at root of threads (A_r) used to compute strengths for tension and single shear with threads in shear plane using the nominal minor diameter for external threads (Class 2A) given in ASME B1.1-1989; $A_r = (\pi/4)(D - 1.191/n)^2$. Area of basic major diameter $(\pi/4)D^2$ used to compute strengths for single shear with no threads in shear plane.
3. Obtain design strengths by dividing the strengths in this table by the appropriate safety factor or multiplying by the appropriate resistance factor (see Part I).
4. Strengths in this table were computed using:
for 2024-T4, $F_{tu} = 62$ ksi and $F_{su} = 37$ ksi;
for 7075-T73, $F_{tu} = 68$ ksi and $F_{su} = 41$ ksi.

Table 5-4
BOLT DIMENSIONS

(American Standard B18.2)



DIMENSIONS IN INCHES

a. Cap Screws – Finished Hexagon Head Bolts

(ANSI Standard B18.2.1)

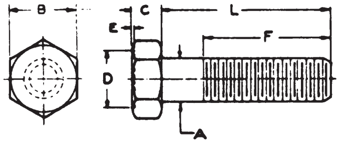
Threads are Class 2A free fit.
Bright finish, up to ¾ in. diam. and/or up to 4 in. length.
Larger sizes, machine finish.

Nominal size or basic major diameter	Thread size	Length, ranges in.*	Body diameter A in.	Width across flats B in.	Head height C in.	Under Head Fillet Radius in.	Thread Length Usable ① ‡	F. in. ② ‡
¼	¼-20	½ to 4¾	0.2500 0.2450	7/16	5/32	0.009 0.023	¾	—
5/16	5/16-18	½ to 6	0.3125 0.3065	½	13/64	0.009 0.023	⅞	—
⅜	⅜-16	½ to 7	0.3750 0.3690	9/16	15/64	0.009 0.023	1	1¼
½	½-13	¾ to 8	0.5000 0.4930	¾	5/16	0.009 0.023	1¼	1½
⅝	⅝-11	1 to 8	0.6250 0.6170	15/16	25/64	0.021 0.041	1½	1¾
¾	¾-10	1 to 8	0.7500 0.7410	1⅛	15/32	0.041 0.062	1¾	2
⅞	⅞-9	2 to 8	0.8750 0.8660	1 5/16	35/64	0.041 0.062	2	2¼
1	1 -8	2 to 8	1.0000 0.9900	1½	39/64	0.062 0.093	2¼	2½

* Available in 1/8 in. increments to one inch length and ¼ in. increments for lengths over one inch.
‡ ① Bolts 6 in. in length and less, ② Bolts over 6 in. in length.

b. Economy Bolts—Special Hexagon Head Bolts

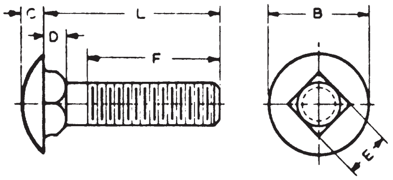
(These special bolts with upset heads are in most cases an economical and satisfactory substitute for finished head bolts)
Threads are Class 2A free fit.
Bright finish up to ¾ in. diam. and/or up to 4 in. in length.
Larger sizes, machine finish.



Nominal size or basic major diameter †	Thread size	Length, ranges in.*	Body diameter A in.	Width across flats B in.	Head height C in.	Approximate diameter recess D in.	Approximate depth recess E in.
10	10-24	½ to 4	0.1900 0.1835	5/16	7/64	0.260	0.010
¼	¼-20	½ to 4¾	0.2500 0.2435	7/16	11/64	0.375	0.010
5/16	5/16-18	½ to 6	0.3125 0.3055	½	7/32	0.416	0.012
⅜	⅜-16	½ to 7	0.3750 0.3675	9/16	¼	0.468	0.016
½	½-13	¾ to 7½	0.5000 0.4930	¾	11/32	0.625	0.019
⅝	⅝-11	1 to 7½	0.6250 0.6170	15/16	27/64	0.781	0.025
¾	¾-10	1 to 7½	0.7500 0.7410	1⅛	½	0.938	0.031
⅞	⅞-9	1 to 7¼	0.875 0.867	1 5/16	37/64	1.078	0.035
1	1-8	1 to 7¼	1.000 0.991	1½	21/32	1.234	0.042

* Available in 1/8 in. increments to one inch length and ¼ in. increments for lengths over one inch.
† The maximum radius of the under head fillet is 1/32 in. for sizes up through ½ in., 1/16 in. for sizes 5/8 in. through 7/8 in. and 3/32 in. in. for the one inch size.

Table 5-4
BOLT DIMENSIONS (Continued)



c. Carriage Bolts, Round Head Square Neck
(ANSI Standard B18.5)

Threads are Class 2A free fit.

Bright finish

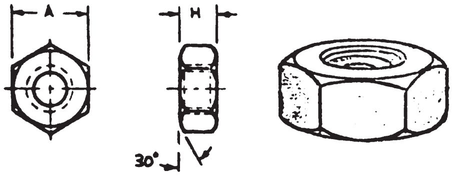
Nominal size or basic major diameter †	Thread size ‡	Length ranges in.*	Head diameter (minimum) B in.	Head height (minimum) C in.	Minimum depth of square D in.	Width of square (maximum) E in.	Minimum thread length F in.	
							Bolts 6 in. in length and less.	Bolts over 6 in. in length.
10	10-24	½ to 4	7/16	3/32	3/32	0.199	⅜	—
¼	¼-20	½ to 4¾	9/16	⅛	⅛	0.260	¾	—
5/16	5/16-18	¾ to 6	11/16	5/32	5/32	0.324	⅞	—
⅜	⅜-16	¾ to 7	25/32	3/16	3/16	0.388	1	1¼
½	½-13	1 to 8	1 1/32	¼	¼	0.515	1¼	1½
⅝	⅝-11	1½ to 8	1 7/32	5/16	5/16	0.642	1½	1¾
¾	¾-10	1½ to 8	1 15/32	⅜	⅜	0.768	1¾	2
⅞	⅞-9	2 to 8	1 23/32	7/16	7/16	0.895	2	2¼
1	1-8	2 to 8	1 31/32	½	½	1.022	2¼	2½

* Available in 1/16 in. increments to one inch length and 1/8 in. increments over one inch.
† Radius of fillet under head of bolt for sizes No. 10 to ½ inch inclusive is 1/64 to 1/32 inch, and for larger sizes is 1/32 to 1/16 inch
‡ Bolts have rolled threads and undersize unthreaded section.

Table 5-5
NUT DIMENSIONS

a. Hexagon Bolt Nuts
Double-Chamfered, Double Countersunk
(ANSI Standard B18.2.2)

All threads are Class 2B free fit.



Nominal size in.	Threads per inch coarse	Width across flats A in.	Thickness H in.	Approximate weight (lb) per 1000 pieces
1/4	20	7/16	7/32	2.81
5/16	18	1/2	17/64	4.14
3/8	16	9/16	21/64	6.10
1/2	13	3/4	7/16	14.3
5/8	11	15/16	35/64	27.9
3/4	10	1 1/8	41/64	46.6
7/8	9	1 5/16	3/4	74.0
1	8	1 1/2	55/64	110.
1 1/8	7	1 11/16	31/32	158.
1 1/4	7	1 7/8	1 1/16	212.

b. Square Bolt Nuts
Top Chamfered
(ANSI Standard B18.2.2)
All threads are Class 2B free fit.

Nominal size in.	Threads per in. coarse	Width across flats A in.	Thickness H in.	Approximate weight (lb) per 1000 pieces
1/4	20	7/16	7/32	3.40
5/16	18	9/16	17/64	6.95
3/8	16	5/8	21/64	9.97
1/2	13	13/16	7/16	22.0
5/8	11	1	35/64	43.4
3/4	10	1 1/8	21/32	59.1
7/8	9	1 5/16	49/64	93.7
1	8	1 1/2	7/8	140.

Table 5-6
INTERNAL THREAD STRIPPING AREA FOR CLASS 2B UNC THREADS

Nominal Size Threads/in.	Nominal Diameter (in.)	Internal Thread Stripping Area A_{sn} (in^2/in. of engagement)
8–32	0.164	0.334
10–24	0.190	0.401
12–24	0.216	0.458
1/4–20	0.250	0.539
5/16–18	0.3125	0.682
3/8–16	0.375	0.828

Table 6-1
ASD ALLOWABLE TENSILE STRESSES FOR GROOVE WELDS (BUILDING-TYPE STRUCTURES)

		Filler						
		1100	**4043**	**5183**	**5356**	**5554**	**5556**	**5654**
		Filler allowable tensile stress (ksi) (note 1)						
Base Metal	Base metal allowable tensile stress (ksi) (note 2)	**5.6**	**12.3**	**20.5**	**17.9**	**15.9**	**21.5**	**15.4**
1100	5.6	5.6	5.6					
3003	7.2	**5.6**	7.2					
Alclad 3003	6.7	**5.6**	6.7					
3004	11.3			11.3	11.3		11.3	
Alclad 3004	10.8			10.8	10.8		10.8	
5005	7.7		7.7	7.7	7.7		7.7	
5050	9.2		9.2	9.2	9.2		9.2	
5052	12.8			12.8	12.8		12.8	
5083	20.0			20.0			20.0	
5086	17.9			17.9	17.9		17.9	
5154	15.4			15.4	15.4		15.4	15.4
5454	15.9			15.9	15.9	15.9	15.9	
5456	21.0			**20.5**			21.0	
6005, 6005A	12.3		12.3	12.3	12.3		12.3	
6061, 6351	12.3		12.3	12.3	12.3		12.3	
6063, 6463	8.7		8.7	8.7	8.7		8.7	
6082	14.4		**12.3**	14.4	14.4		14.4	
7005	20.5			20.5	**17.9**		20.5	

Table 6-1M
ASD ALLOWABLE TENSILE STRESSES FOR GROOVE WELDS (BUILDING-TYPE STRUCTURES)

		Filler						
		1100	**4043**	**5183**	**5356**	**5554**	**5556**	**5654**
		Filler allowable tensile stress (MPa) (note 1)						
Base Metal	Base metal allowable tensile stress (MPa) (note 2)	**38**	**85**	**141**	**123**	**110**	**149**	**105**
1100	38	38	38					
3003	49	**38**	49					
Alclad 3003	46	**38**	46					
3004	77			77	77		77	
Alclad 3004	74			74	74		74	
5005	54		54	54	54		54	
5050	64		64	64	64		64	
5052	87			87	87		87	
5083	138			138			138	
5086	123			123	123		123	
5154	105			105	105		105	105
5454	110			110	110	110	110	
5456	146			**141**			146	
6005, 6005A	85		85	85	85		85	
6061, 6351	85		85	85	85		85	
6063, 6463	59		59	59	59		59	
6082	97		**85**	97	97		97	
7005	141			141	**123**		141	

Notes for Table 6-1 and 6-1M:
1. Allowable tensile stress for filler = $F_{tuw}/1.95$
2. Allowable tensile stress for base metal = $F_{tuw}/1.95$
3. Allowable stresses are for the base metal welded to itself.
4. **Bold** values indicate the filler governs the joint strength.

Table 6-2
ASD ALLOWABLE SHEAR STRESSES FOR FILLET WELDS (BUILDING-TYPE STRUCTURES)

		Filler						
		1100	**4043**	**5183**	**5356**	**5554**	**5556**	**5654**
		Filler allowable shear stress (ksi) (note 1)						
Base Metal	Base metal allowable shear stress (ksi) (note 2)	**3.8**	**5.9**	**10.8**	**8.7**	**8.7**	**10.3**	**6.2**
1100	5.8	**3.8**	5.8					
3003	7.3	**3.8**	**5.9**					
Alclad 3003	7.3	**3.8**	**5.9**					
3004	10.2			10.2	**8.7**		10.2	
Alclad 3004	9.4			9.4	**8.7**		9.4	
5005	6.5		**5.9**	6.5	6.5		6.5	
5050	8.7		**5.9**	8.7	**8.7**		8.7	
5052	11.6			**10.8**	**8.7**		**10.3**	
5083	16.7			**10.8**			**10.3**	
5086	15.2			**10.8**	**8.7**		**10.3**	
5154	13.8			**10.8**	**8.7**		**10.3**	**6.2**
5454	13.8			**10.8**	**8.7**	**8.7**	**10.3**	
5456	18.1			**10.8**			**10.3**	
6005, 6005A	10.9		**5.9**	**10.8**	**8.7**		**10.3**	
6061, 6351	10.9		**5.9**	**10.8**	**8.7**		**10.3**	
6063, 6463	8.0		**5.9**	8.0	8.0		8.0	
6082	10.9		**5.9**	**10.8**	**8.7**		**10.3**	
7005	16.0			**10.8**	**8.7**		**10.3**	

Table 6-2M
ASD ALLOWABLE SHEAR STRESSES FOR FILLET WELDS (BUILDING-TYPE STRUCTURES)

		Filler						
		1100	**4043**	**5183**	**5356**	**5554**	**5556**	**5654**
		Filler allowable shear stress (MPa) (note 1)						
Base Metal	Base metal allowable shear stress (MPa) (note 2)	**26**	**41**	**74**	**59**	**59**	**72**	**44**
1100	40	**26**	40					
3003	51	**26**	**41**					
Alclad 3003	51	**26**	**41**					
3004	69			69	**59**		69	
Alclad 3004	65			65	**59**		65	
5005	45		**41**	45	45		45	
5050	62		**41**	62	**59**		62	
5052	80			**74**	**59**		**72**	
5083	116			**74**			**72**	
5086	105			**74**	**59**		**72**	
5154	94			**74**	**59**		**72**	**44**
5454	94			**74**	**59**	**59**	**72**	
5456	123			**74**			**72**	
6005, 6005A	76		**41**	**74**	**59**		**72**	
6061, 6351	76		**41**	**74**	**59**		**72**	
6063, 6463	54		**41**	54	54		54	
6082	76		**41**	**74**	**59**		**72**	
7005	112			**74**	**59**		**72**	

Notes for Table 6-2 and 6-2M:
1. Allowable shear stress for filler = $F_{suw}/1.95$
2. Allowable shear stress for base metal = $F_{suw}/(1.95 \cos 45°)$
3. Allowable stresses are for the base metal welded to itself.
4. **Bold** values indicate the filler governs the joint strength.
5. Compute stresses on the effective throat of the fillet.

Table 6-3

LRFD DESIGN TENSILE STRESSES FOR GROOVE WELDS (BUILDING-TYPE STRUCTURES)

		Filler						
		1100	**4043**	**5183**	**5356**	**5554**	**5556**	**5654**
		Filler design tensile stress (ksi) (note 1)						
Base Metal	Base metal design tensile stress (ksi) (note 2)	**8.3**	**18.0**	**30.0**	**26.3**	**23.3**	**31.5**	**22.5**
1100	8.3	8.3	8.3					
3003	10.5	**8.3**	10.5					
Alclad 3003	9.8	**8.3**	9.8					
3004	16.5			16.5	16.5		16.5	
Alclad 3004	15.8			15.8	15.8		15.8	
5005	11.3		11.3	11.3	11.3		11.3	
5050	13.5		13.5	13.5	13.5		13.5	
5052	18.8			18.8	18.8		18.8	
5083	30.0			30.0			30.0	
5086	26.3			26.3	26.3		26.3	
5154	22.5			22.5	22.5		22.5	22.5
5454	23.3			23.3	23.3	23.3	23.3	
5456	31.5			**30.0**			31.5	
6005, 6005A	18.0		18.0	18.0	18.0		18.0	
6061, 6351	18.0		18.0	18.0	18.0		18.0	
6063, 6463	12.8		12.8	12.8	12.8		12.8	
6082	21.0		**18.0**	21.0	21.0		21.0	
7005	30.0			30.0	**26.3**		30.0	

Table 6-3M
LRFD DESIGN TENSILE STRESSES FOR GROOVE WELDS (BUILDING-TYPE STRUCTURES)

		Filler						
		1100	**4043**	**5183**	**5356**	**5554**	**5556**	**5654**
		Filler design tensile stress (MPa) (note 1)						
Base Metal	Base metal design tensile stress (MPa) (note 2)	**56**	**124**	**206**	**180**	**161**	**218**	**154**
1100	56	56	56					
3003	71	**56**	71					
Alclad 3003	68	**56**	68					
3004	113			113	113		113	
Alclad 3004	109			109	109		109	
5005	79		79	79	79		79	
5050	94		94	94	94		94	
5052	128			128	128		128	
5083	203			203			203	
5086	180			180	180		180	
5154	154			154	154		154	154
5454	161			161	161	161	161	
5456	214			**206**			214	
6005, 6005A	124		124	124	124		124	
6061, 6351	124		124	124	124		124	
6063, 6463	86		86	86	86		86	
6082	143		**124**	143	143		143	
7005	206			206	**180**		206	

Notes for Table 6-3 and 6-3M:
1. Design tensile stress for filler = $0.75F_{tuw}$
2. Design tensile stress for base metal = $0.75F_{tuw}$
3. Design stresses are for the base metal welded to itself.
4. **Bold** values indicate the filler governs the joint strength.

Table 6-4
LRFD DESIGN SHEAR STRESSES FOR FILLET WELDS (BUILDING-TYPE STRUCTURES)

		Filler						
		1100	4043	5183	5356	5554	5556	5654
		Filler design shear stress (ksi) (note 1)						
Base Metal	Base metal design shear stress (ksi) (note 2)	**5.6**	**8.6**	**15.8**	**12.8**	**12.8**	**15.0**	**9.0**
1100	8.5	**5.6**	8.5					
3003	10.6	**5.6**	**8.6**					
Alclad 3003	10.6	**5.6**	**8.6**					
3004	14.8			14.8	**12.8**		14.8	
Alclad 3004	13.8			13.8	**12.8**		13.8	
5005	9.5		**8.6**	9.5	9.5		9.5	
5050	12.7		**8.6**	12.7	12.7		12.7	
5052	17.0			**15.8**	**12.8**		**15.0**	
5083	25.5			**15.8**			**15.0**	
5086	22.3			**15.8**	**12.8**		**15.0**	
5154	20.2			**15.8**	**12.8**		**15.0**	**9.0**
5454	20.2			**15.8**	**12.8**	**12.8**	**15.0**	
5456	27.6			**15.8**			**15.0**	
6005, 6005A	15.9		**8.6**	**15.8**	**12.8**		**15.0**	
6061, 6351	15.9		**8.6**	**15.8**	**12.8**		**15.0**	
6063, 6463	11.7		**8.6**	11.7	11.7		11.7	
6082	15.9		**8.6**	**15.8**	**12.8**		**15.0**	
7005	23.3			**15.8**	**12.8**		**15.0**	

Table 6-4M
LRFD DESIGN SHEAR STRESSES FOR FILLET WELDS (BUILDING-TYPE STRUCTURES)

		Filler						
		1100	4043	5183	5356	5554	5556	5654
		Filler design shear stress (MPa) (note 1)						
Base Metal	Base metal design shear stress (MPa) (note 2)	**38**	**60**	**109**	**86**	**86**	**105**	**64**
1100	58	**38**	58					
3003	74	**38**	**60**					
Alclad 3003	74	**38**	**60**					
3004	101			101	**86**		101	
Alclad 3004	95			95	**86**		95	
5005	66		**60**	66	66		66	
5050	90		**60**	90	**86**		90	
5052	117			**109**	**86**		**105**	
5083	175			**109**			**105**	
5086	154			**109**	**86**		**105**	
5154	138			**109**	**86**		**105**	**64**
5454	138			**109**	**86**	**86**	**105**	
5456	180			**109**			**105**	
6005, 6005A	111		**60**	**109**	**86**		**105**	
6061, 6351	111		**60**	**109**	**86**		**105**	
6063, 6463	80		**60**	80	80		80	
6082	111		**60**	**109**	**86**		**105**	
7005	164			**109**	**86**		**105**	

Notes for Table 6-4 and 6-4M:
1. Design shear stress for filler = 0.75F_{suw}
2. Design shear stress for base metal = 0.75F_{suw}/cos45°
3. Design stresses are for the base metal welded to itself.
4. **Bold** values indicate the filler governs the joint strength.
5. Compute stresses on the effective throat of the fillet.

BEAM FORMULAS

BEAMS

Flexural stress at extreme fiber: $f = Mc/I = M/S$
M = bending moment
I = moment of inertia
$S = I/c$ = section modulus
c = distance to extreme fiber

Flexural stress at any fiber: $f = My/I$
y = distance from neutral axis to fiber.

Average vertical shear stress: $v = V/A$
V = shear load
A = area of cross section

Horizontal shearing stress at any section A-A: $v = VQ/I\,b$
Q = static moment about the neutral axis of the entire section of that portion of the cross section lying outside of section A-A
b = width at section A-A

(Intensity of vertical shear is equal to that of horizontal shear acting normal to it at the same point and both are usually a maximum at mid-height of beam.)

Slope and deflection at any point: $EI\dfrac{d^2y}{dx^2} = M$ (Basic differential equation for beam)

x and y are abscissa and ordinate respectively of a point on the neutral axis, referred to axes of rectangular co-ordinates through a selected point of support. (First integration gives slopes; second integration gives deflections. Constants of integration must be determined.)

CONTINUOUS BEAMS (Theorem of Three Moments)

Uniform load: $M_a\dfrac{l_1}{I_1} + 2M_b\left(\dfrac{l_1}{I_1}+\dfrac{l_2}{I_2}\right) + M_c\dfrac{l_2}{I_2} = -\tfrac{1}{4}\left(\dfrac{w_1l_1^3}{I_1}+\dfrac{w_2l_2^3}{I_2}\right)$

Concentrated loads:

$$M_a\frac{l_1}{I_1} + 2M_b\left(\frac{l_1}{I_1}+\frac{l_2}{I_2}\right) + M_c\frac{l_2}{I_2} = -\frac{P_1a_1b_1}{I_1}\left(1+\frac{a_1}{l_1}\right) - \frac{P_2a_2b_2}{I_2}\left(1+\frac{b_2}{l_2}\right)$$

Considering any two consecutive spans in any continuous structure:

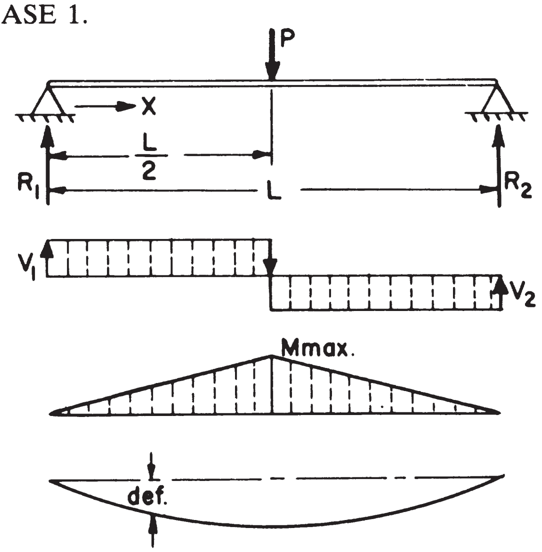
M_a, M_b, M_c = moments at left, center, and right supports, respectively, of any pair of adjacent spans.
l_1 and l_2 = lengths of left and right spans, respectively, of the pair.
I_1 and I_2 = moments of inertia of left and right spans, respectively.
w_1 and w_2 = loads per unit of length on left and right spans, respectively.
P_1 and P_2 = concentrated loads on left and right spans, respectively.
a_1 and a_2 = distance of concentrated loads from left support in left and right spans, respectively.
b_1 and b_2 = distance of concentrated loads from right support in left and right spans, respectively.

The above equations are for beams with moment of inertia constant in each span but differing in different spans, continuous over three or more supports. By writing such an equation for each successive pair of spans and introducing the known values (usually zero) of end moments, all other moments can be found.

COLUMNS

Concentrically loaded: stress $f = P/A$; P = column load, A = area of cross section
Eccentrically loaded: stress $f = P/A + Mc/I = P/A\,(1 + ec/r^2)$
Bending in plane of principal axis. Deflection not considered.
e = eccentricity of load, r = radius of gyration.

CASE 1.



Concentrated load P at center

Reactions: $R_1 = R_2 = \frac{P}{2}$

Maximum shear forces:

$$V_1 = +P/2;\ V_2 = -P/2$$

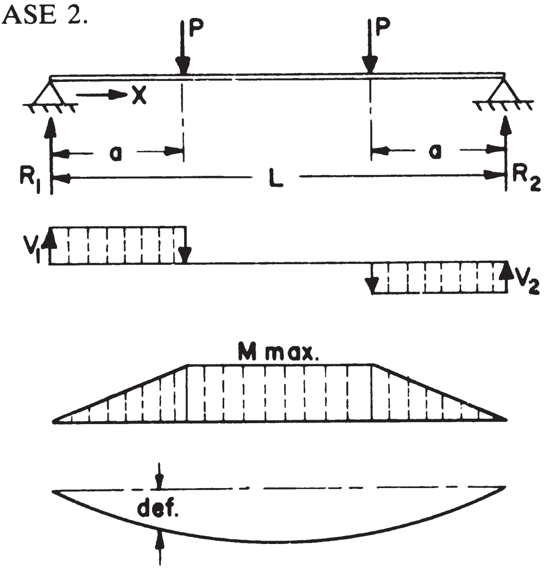
Maximum bending moment:

$$M_{\max} = \frac{PL}{4} \text{ at center}$$

Maximum deflection $= \frac{PL^3}{48EI}$ at center

$$\text{def.} = \frac{Px}{48EI}(3L^2 - 4x^2),\quad o \le x \le \frac{L}{2}$$

CASE 2.



Two equal concentrated loads P equi-distant from the center

Reactions: $R_1 = R_2 = P$

Maximum shear forces:

$$V_1 = +P\ ;\ V_2 = -P$$

Maximum bending moment:

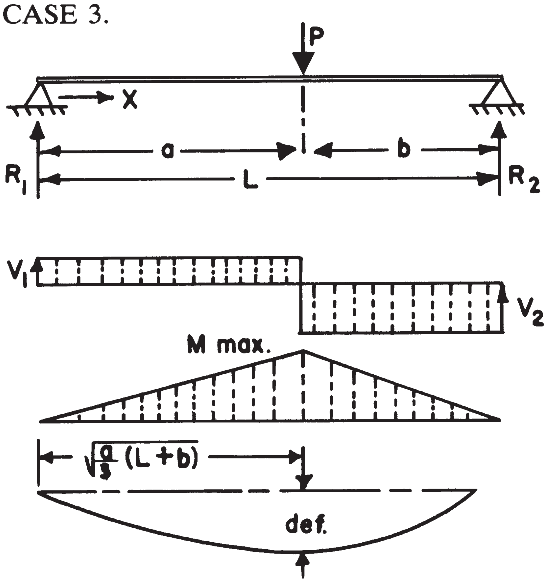
$$M_{\max} = Pa, \text{ between loads}$$

Maximum deflection $= \frac{Pa}{24EI}(3L^2 - 4a^2)$

$$\text{def.} = \frac{Px}{6EI}(3La - 3a^2 - x^2),\quad o \le x \le a$$

$$= \frac{Pa}{6EI}(3Lx - 3x^2 - a^2),\quad a \le x \le (L - a)$$

CASE 3.



Concentrated load P at any point

Reactions: $R_1 = \frac{Pb}{L};\ R_2 = \frac{Pa}{L}$

Shear forces: $V_1 = +R_1;\ V_2 = -R_2$

Maximum bending moment:

$$M_{\max} = \frac{Pab}{L}, \text{ at } x = a$$

$$M = \frac{Pbx}{L},\ o \le x \le a;\ M = \frac{Pa}{L}(L - x),\ a \le x \le L$$

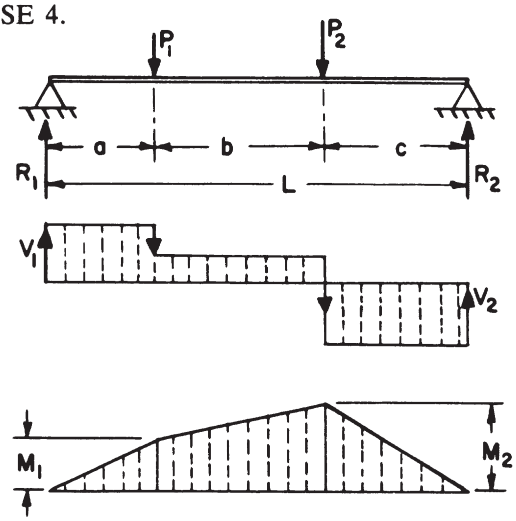
Maximum deflection $= \frac{Pab\,(L + b)\sqrt{3a\,(L + b)}}{27\,EIL}$

at $x = \sqrt{a\,(L + b)/3}$ when $a > b$

deflection under load $= \frac{Pa^2b^2}{3\,EIL},\quad x = a$

$$\text{def.} = \frac{Pbx}{6\,EIL}(L^2 - b^2 - x^2),\quad o \le x \le a$$

CASE 4.



Two *unequal* concentrated loads unsymmetrically located

$$\text{Reactions: } R_1 = \frac{P_1(L-a) + P_2c}{L}$$

$$R_2 = \frac{P_2(L-c) + P_1a}{L}$$

Shear forces: $V_1 = +R_1$

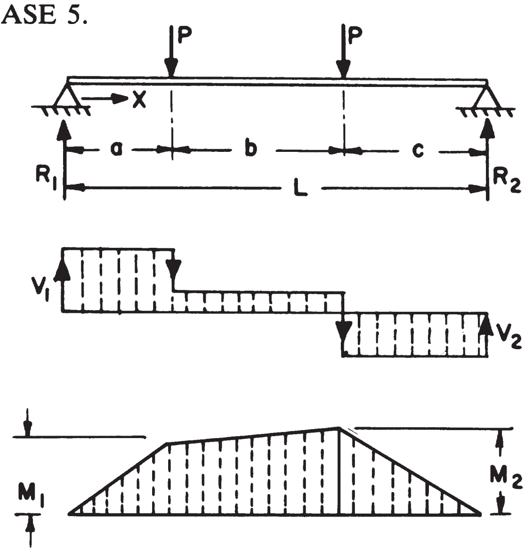
$V_2 = -R_2$

Bending moments:

$M_1 = R_1a$, maximum if $R_1 < P_1$

$M_2 = R_2c$, maximum if $R_2 < P_2$

CASE 5.



Two *equal* concentrated loads unsymmetrically located

$$\text{Reactions: } R_1 = \frac{P(L-a+c)}{L}$$

$$R_2 = \frac{P(L-c+a)}{L}$$

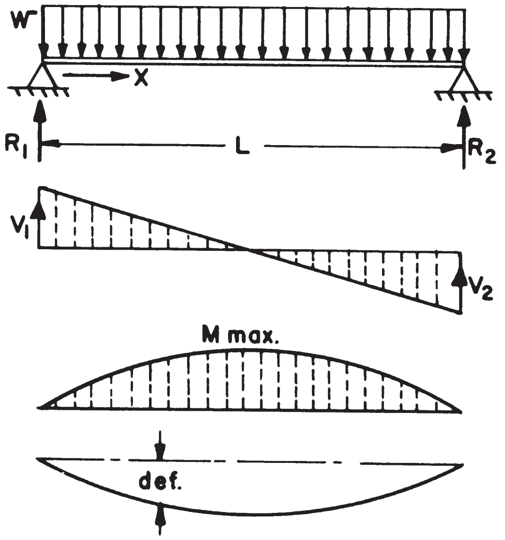
Shear forces: $V_1 = +R_1$
$V_2 = -R_2$

Bending moments:

$M_1 = R_1a$, maximum if $a > c$
$M_2 = R_2c$, maximum if $a < c$

$M = R_1x - P(x-a), \quad a \leq x \leq (a+b)$

CASE 6.



Uniformly distributed loading of w lb/in total load $W = wL$

$$\text{Reactions: } R_1 = R_2 = \frac{wL}{2} = \frac{W}{2}$$

$$\text{Shear} = w\left(\frac{L}{2} - x\right), \quad o \leq x \leq L$$

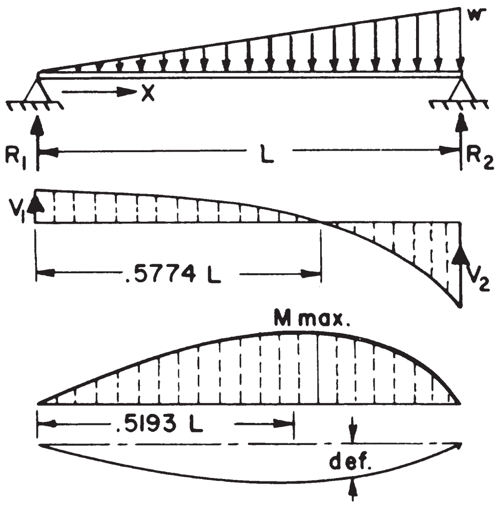
$$\text{Maximum bending moment} = \frac{wL^2}{8} = \frac{WL}{8}, \text{ at center}$$

$$M = \frac{wx}{2}(L-x) = \frac{Wx}{2L}(L-x), \quad o \leq x \leq L$$

$$\text{Maximum deflection} = \frac{5\,wL^4}{384\,EI} = \frac{5\,WL^3}{384\,EI}, \text{ at center}$$

$$\text{def.} = \frac{wx}{24\,EI}(L^3 - 2Lx^2 + x^3), \quad o \leq x \leq L$$

CASE 7.



Distributed load increasing uniformly to one end

Total load $W = \frac{wL}{2}$, max. loading = w lb/in

Reactions: $R_1 = \frac{W}{3} = \frac{wL}{6}$

$R_2 = \frac{2W}{3} = \frac{wL}{3}$

Shear forces: $V_1 = +R_1; V_2 = -R_2$

$V = \frac{W}{3} - \frac{Wx^2}{L^2}, o \leq x \leq L$

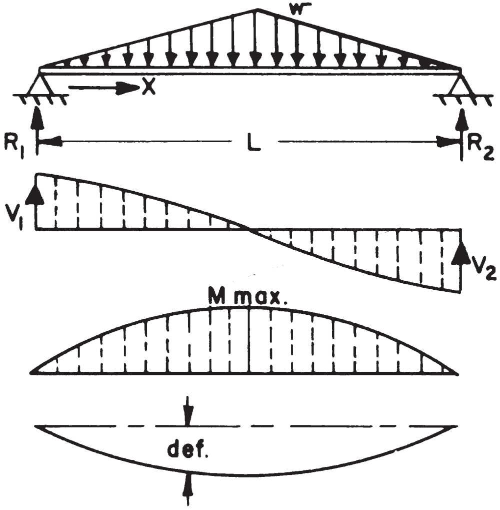
Maximum bending moment $= 0.1283WL, x = 0.5774L$

$M = \frac{Wx}{3L^2}(L^2 - x^2), o \leq x \leq L$

Maximum deflection $= 0.01304 \frac{WL^3}{EI}, x = 0.5193L$

def. $= \frac{Wx}{180\ EIL^2}(3x^4 - 10L^2x^2 + 7L^4), \quad o \leq x \leq L$

CASE 8.



Distributed load increasing toward center

Total load W $= \frac{wL}{2}$, max. loading = w lb/in

Reactions: $R_1 = R_2 = \frac{W}{2} = \frac{wL}{4}$

Shear forces: $V_1 = +R_1 ; V_2 = -R_2$

$V = \frac{W}{2L^2}(L^2 - 4x^2), o \leq x \leq \frac{L}{2}$

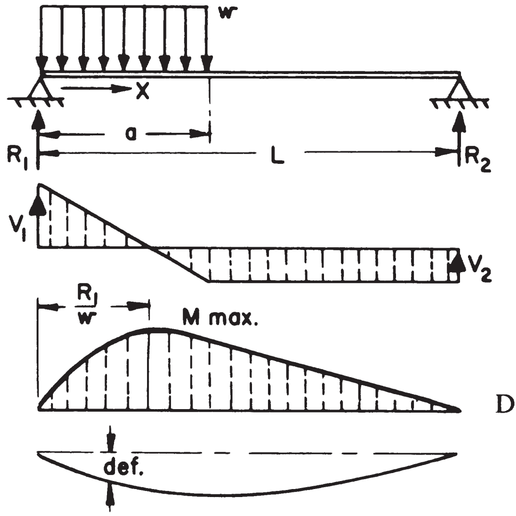
Maximum bending moment $= \frac{WL}{6} = \frac{wL^2}{12}$

$M = \frac{Wx}{2}\left(1 - \frac{4x^2}{3L^2}\right), \quad o \leq x \leq \frac{L}{2}$

Maximum deflection $= \frac{WL^3}{60\ EI} = \frac{wL^4}{120\ EI}, x = \frac{L}{2}$

def. $= \frac{Wx}{480\ EIL^2}(5L^2 - 4x^2)^2, \quad o \leq x \leq \frac{L}{2}$

CASE 9.



Load uniformly distributed at left end of beam

Total load = wa

Reactions: $R_1 = \frac{wa}{2L}(2L - a); R_2 = \frac{wa^2}{2L}$

Shear forces: $V_1 = +R_1; V_2 = -R_2$

$V = R_1 - wx, o \leq x \leq a$

Maximum bending moment:

$= \frac{wa^2}{8L^2}(2L - a)^2, x = \frac{R_1}{w}$

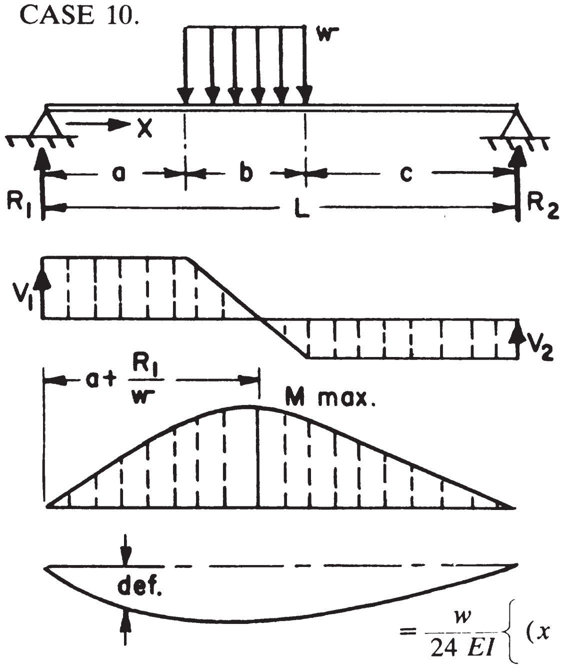
$M = R_1x - \frac{wx^2}{2}, o \leq x \leq a$

Def. $= \frac{wx}{24\ EIL}[a^2(2L - a)^2 - 2ax^2(2L - a) + Lx^3],$

$o \leq x \leq a$

$= \frac{wa^2(L - x)}{24\ EIL}(4Lx - 2x^2 - a^2), a \leq x \leq L$

CASE 10.



Partially distributed uniform load

Total load = wb

Reactions: $R_1 = \dfrac{wb}{2L}(2c + b)$

$R_2 = \dfrac{wb}{2L}(2a + b)$

Shear forces: $V_1 = +R_1\,;\; V_2 = -R_2$

$V = R_1 - w(x - a),\; a \leq x \leq a + b$

Maximum bending moment

$$= \frac{wb}{8L^2}(2c + b)\,[4aL + b\,(2c + b)],\; x = a + \frac{R_1}{w}$$

Deflection:

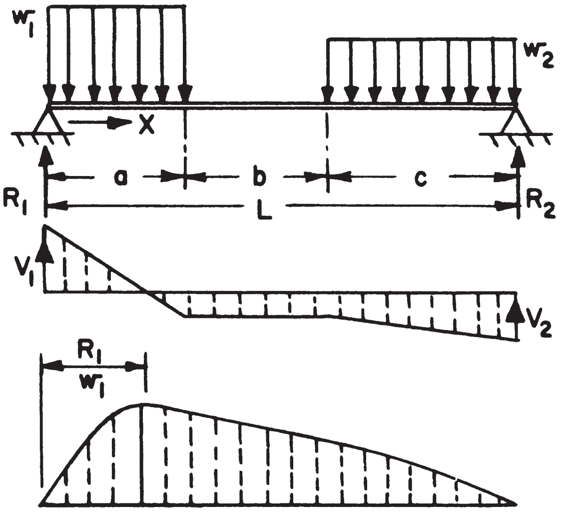
$$= \frac{w}{24\,EI}\left[\frac{b\,(b + 2c)x}{L}\right]\left[-\,2x^2 + 2a\,(2L - a) + b\,(b + 2c)\right]$$

for $o \leq x \leq a$

$$= \frac{w}{24\,EI}\left\{(x - a)^4 + \left[\frac{b\,(b + 2c)x}{L}\right]\left[-\,2x^2 + 2a\,(2L - a) + b\,(b + 2c)\right]\right\}$$

for $a \leq x \leq a + b$

CASE 11.



Partially distributed uniform load at each end

Total load = $w_1a + w_2c$

Reactions: $R_1 = \dfrac{w_1a\,(2L - a) + w_2c^2}{2L}$

$R_2 = \dfrac{w_2c\,(2L - c) + w_1a^2}{2L}$

Shear forces: $V_1 = +R_1\,;\; V_2 = -R_2$

Maximum bending moment

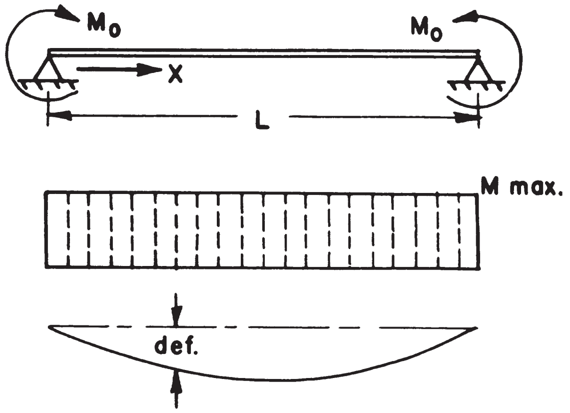
$= \dfrac{R_1{}^2}{2w_1}$, when $R_1 < w_1a$

$M = R_1x - \dfrac{w_1x^2}{2},\; o \leq x \leq a$

$M = R_1x - \dfrac{w_1a}{2}(2x - a),\; a \leq x \leq a + b$

$M = R_2\,(L - x) - \dfrac{w_2\,(L - x)^2}{2},\; a + b \leq x \leq L$

CASE 12.



Two equal and opposite moments, M₀, at ends

Reactions: both zero

Shear forces: zero at all points

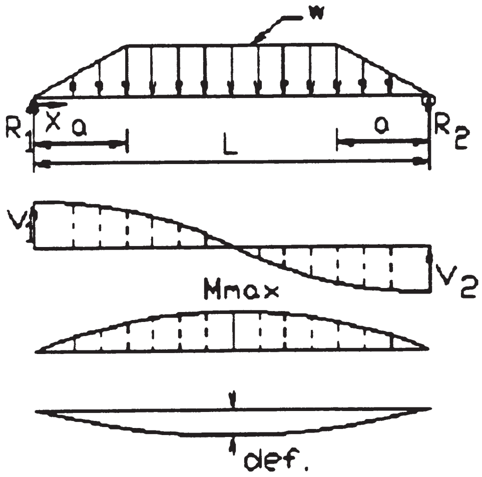
Maximum bending moment = M_o

$M = M_o$ at all points

Maximum deflection = $\dfrac{M_oL^2}{8\,EI},\; x = \dfrac{L}{2}$

def. = $\dfrac{M_ox}{2\,EI}(L - x),\; o \leq x \leq L$

CASE 12A.



Trapezoidally distributed load:

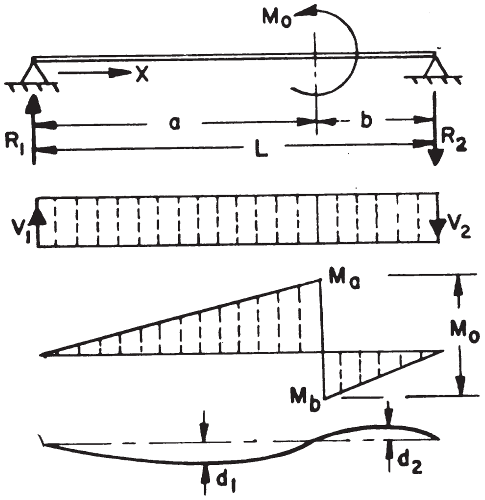
Total Load: $W = w(L - a)$
Max. Load: w lb/in
Reactions: $R_1 = W/2$, $R_2 = W/2$
Shear Forces: $V_1 = R_1$; $V_2 = -R_2$
Maximum bending moment =

$$\frac{w}{24}(3L^2 - 4a^2),\ x = \frac{L}{2}$$

Maximum deflection =

$$\frac{wL^4}{1920EI}\left[25 - 40\left(\frac{a}{L}\right)^2 + 16\left(\frac{a}{L}\right)^4\right],\ x = \frac{L}{2}$$

CASE 13.



Moment, M_o, applied at $x = a$

Reactions: $R_1 = +\frac{M_o}{L}$; $R_2 = -\frac{M_o}{L}$

Shear force $V = +\frac{M_o}{L}, o \leq x \leq L$

Bending moment: $M_a = \frac{M_o a}{L}$, $M_b = -\frac{M_o b}{L}$

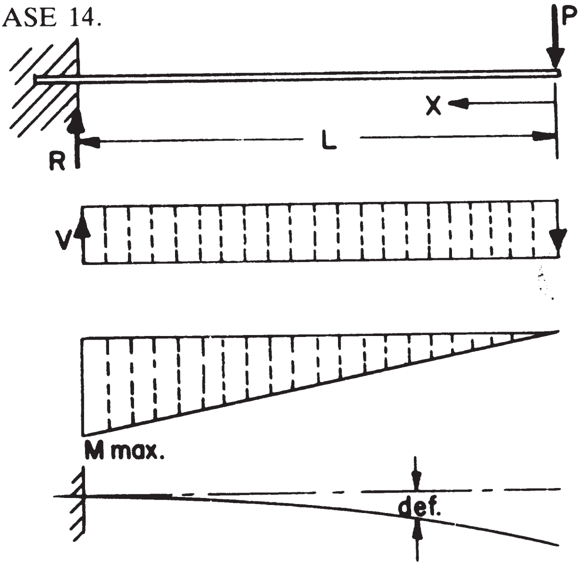
$$M_a - M_b = M_o$$

Deflection:

$$d_1 = \frac{M_o}{6\,EI}\left[\left(6a - \frac{3a^2}{L} - 2L\right)x - \frac{x^3}{L}\right], o \leq x \leq a$$

$$d_2 = \frac{M_o}{6\,EI}\left[3a^2 + 3x^2 - \frac{x^3}{L} - \left(2L + \frac{3a^2}{L}\right)x\right], a \leq x \leq L$$

CASE 14.



Concentrated load, P, at free end of cantilever beam

Reaction: $R = P$, at fixed end

Shear force $V = -P, o \leq x \leq L$

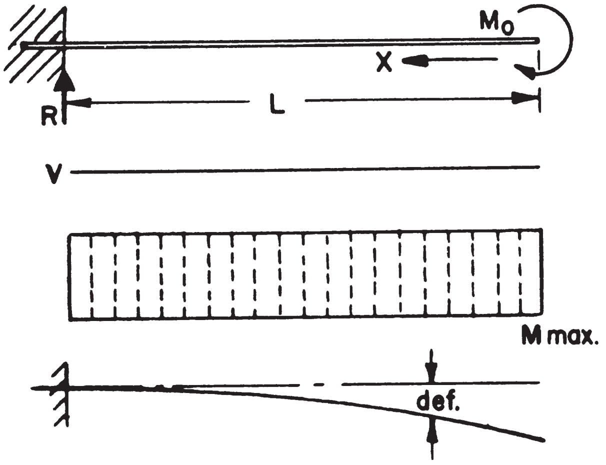
Maximum bending moment $= -PL, x = L$

Bending moment: $M = -Px, o \leq x \leq L$

Maximum deflection $= \frac{PL^3}{3\,EI}$, at free end, $x = o$

$$\text{def.} = \frac{P}{6\,EI}(2L^3 - 3L^2x + x^3), o \leq x \leq L$$

CASE 15.



Moment, $-M_o$, at free end of cantilever beam

Reaction: $R = o$

Shear force: $V = o, o \leq x \leq L$

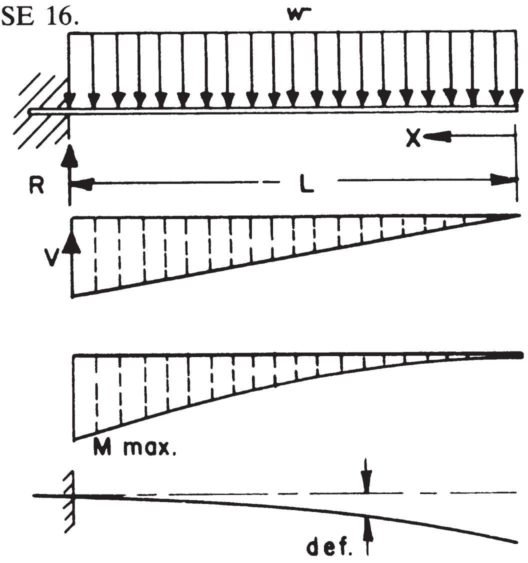
Maximum bending moment $= -M_o$

Bending moment $= -M_o, o \leq x \leq L$

Maximum deflection $= \frac{M_o L^2}{2\,EI}$, at free end

$$\text{def.} = \frac{M_o (L - x)^2}{2\,EI}, o \leq x \leq L$$

CASE 16.



Uniformly distributed loading of w lb/in

Total load $W = wL$

Reaction: $R = W = wL$

Maximum shear force $= -W = -wL$, at $x = L$

Shear force $= -wx, \; o \leq x \leq L$

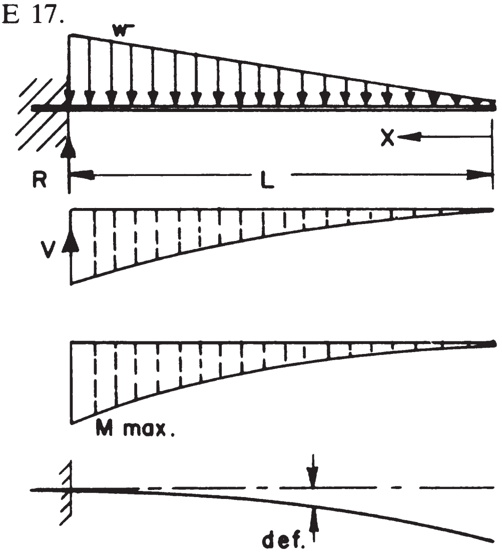
Maximum bending moment $= -\frac{WL}{2} = -\frac{wL^2}{2}$, at fixed end

Bending moment: $M = -\frac{Wx^2}{2L} = -\frac{wx^2}{2}, \; o \leq x \leq L$

Maximum deflection $= \frac{WL^3}{8\,EI} = \frac{wL^4}{8\,EI}$, at free end

$$\text{def} = \frac{w}{24\,EI}(x^4 - 4L^3x + 3L^4), \; o \leq x \leq L$$

CASE 17.



Distributed loading, increasing uniformly to fixed end

Total load $= W = \frac{wL}{2}$

Reaction: $R = W = \frac{wL}{2}$

Maximum shear force $= -W = -\frac{wL}{2}$, at $x = L$

Shear force $= -\frac{Wx^2}{L^2}, \; o \leq x \leq L$

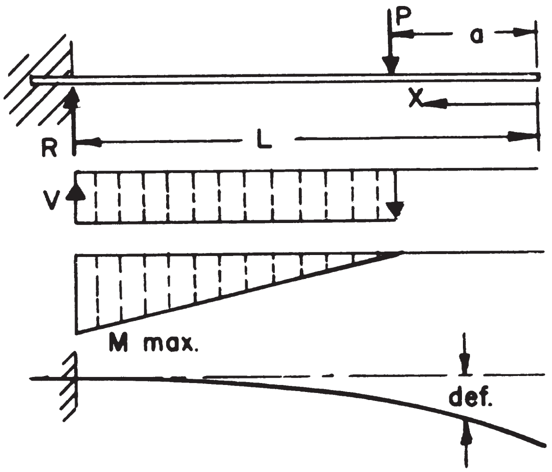
Maximum bending moment $= -\frac{WL}{3}$, at fixed end

Bending moment $= -\frac{Wx^3}{3L^2}, \; o \leq x \leq L$

Maximum deflection $= \frac{WL^3}{15\,EI}$, at free end

$$\text{def.} = \frac{W}{60\,EIL^2}(x^5 - 5L^4x + 4L^5), \; o \leq x \leq L$$

CASE 18.



Concentrated load, P, inboard of free end

Reaction: $R = P$

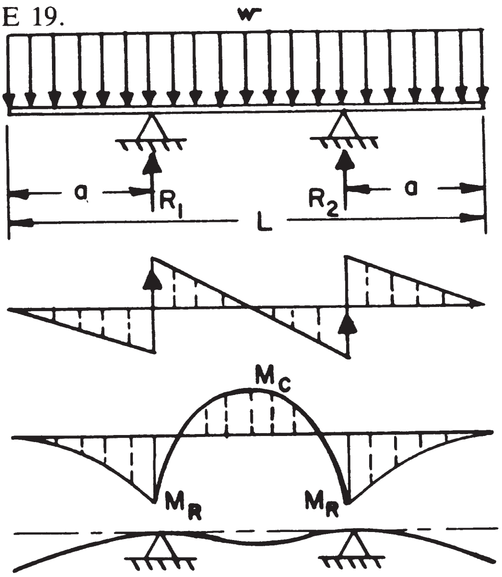
Shear force: $V = 0, \; o \leq x < a$

$V = -P, \; a < x \leq L$

Maximum bending moment $= -P\,(L - a)$, at fixed end

Maximum deflection $= \frac{P\,(L-a)^2}{6\,EI}(2L + a)$

CASE 19.



Uniformly distributed loading of w lb/in

Total load, $W = wL$

Reactions: $R_1 = R_2 = \frac{W}{2}$

Shear forces:

$V = wa$, just outboard of supports

$V = \frac{w}{2}(L - 2a)$, just inboard of supports

Bending moments:

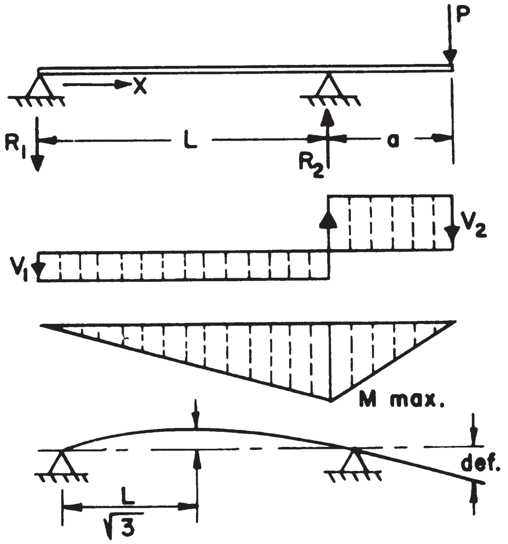
$$M_R = -\frac{wa^2}{2} = -\frac{Wa^2}{2L}, \text{ at supports}$$

$$M_c = \frac{W}{8}(L - 4a), \text{ at center}$$

$$\text{def.} = \frac{W\,(L-2a)^3}{384\,EI}\left[\frac{5}{L}(L - 2a) - \frac{24}{L}\left(\frac{a^2}{L - 2a}\right)\right], \text{ at center}$$

$$\text{def.} = \frac{W\,(L - 2a)^3 a}{24\,EIL}\left[-1 + 6\left(\frac{a}{L - 2a}\right)^2 + 3\left(\frac{a}{L - 2a}\right)^3\right], \text{ at ends}$$

CASE 20.



Concentrated load, P, at end of overhang

Reactions: $R_1 = -\frac{Pa}{L}$

$R_2 = \frac{P}{L}(L + a)$

Shear forces: $V_1 = -\frac{Pa}{L}$

$V_2 = P$

Maximum bending moment:

$M_{max} = -Pa$, at right support

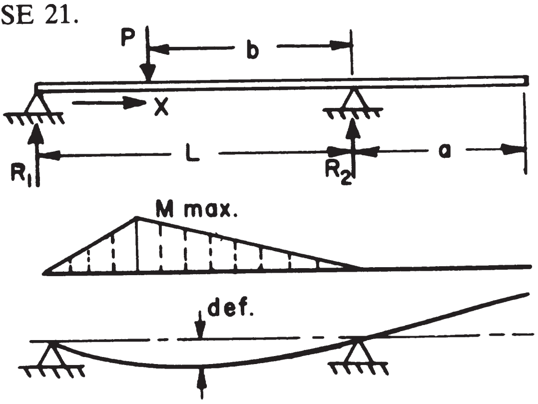
Deflections:

Maximum downward def. $= \frac{Pa^2}{3\,EI}(L + a)$, at load

Maximum upward deflection; at $x = \frac{L}{\sqrt{3}}$

$$= \frac{PaL^2}{9\sqrt{3}\,EI} = 0.06415\,\frac{PaL^2}{EI}$$

CASE 21.



Concentrated load, P, between supports

Reactions: $R_1 = \frac{Pb}{L}$; $R_2 = \frac{P\,(L-b)}{L}$

Maximum bending moment $= \frac{Pb\,(L - b)}{L}$, at load

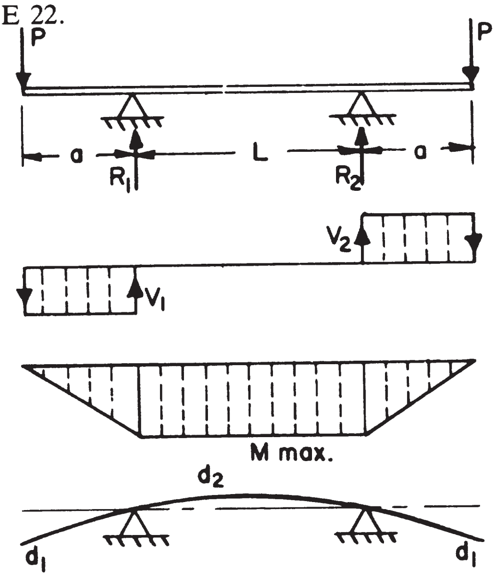
Maximum downward deflection

$$= \frac{Pb\,(L^2 - b^2)\sqrt{3\,(L^2 - b^2)}}{27\,EIL}, \text{ at } x = \frac{\sqrt{3\,(L^2 - b^2)}}{3}$$

Maximum upward deflection

$$= -\frac{Pab}{6\,EI}\left(2L + \frac{b^2}{L} - 3b\right), \text{ at end of overhang}$$

CASE 22.



Two equal loads, P, at ends of overhang

Reactions: $R_1 = R_2 = P$

Shear forces: $V_1 = -P$; $V_2 = +P$

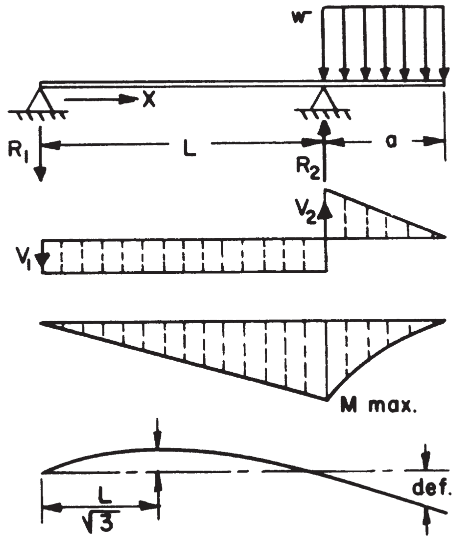
Maximum bending moment $= -Pa$, between supports

Deflections:

$$d_1 = \frac{Pa^2}{3\,EI}\left(a + \frac{3}{2}L\right), \text{ at point of load}$$

$$d_2 = -\frac{PL^2a}{8\,EI}, \text{ at center point}$$

CASE 23.



Uniformly distributed loading, w lb/in on overhang

Total load $= wa$

Reactions: $R_1 = -\dfrac{wa^2}{2L}$

$$R_2 = \frac{wa}{2L}(2L + a)$$

Shear forces: $V_1 = R_1$

$V_2 = wa$

Maximum bending moment:

$$M_{\max} = -\frac{wa^2}{2}, \text{ at right support}$$

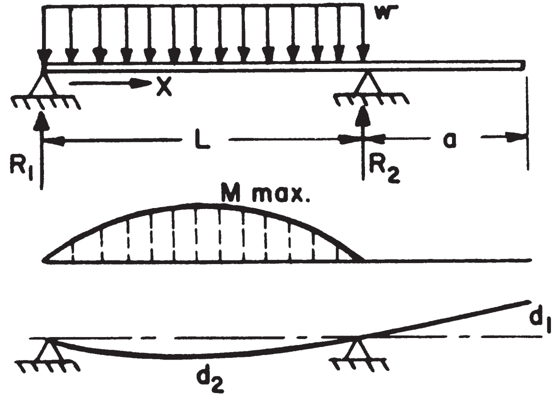
Deflection at end of overhang:

$$d_1 = \frac{wa^3}{24\,EI}(4L + 3a)$$

Maximum deflection between supports:

$$d_2 = -\frac{wa^2L^2}{18\sqrt{3}\,EI} = -0.03208\frac{wa^2L^2}{EI}$$

CASE 24.



Uniformly distributed loading, w lb/in between supports

Total load $= wL$

Reactions: $R_1 = R_2 = \dfrac{wL}{2}$

Maximum bending moment $= \dfrac{wL^2}{8}$, $x = \dfrac{L}{2}$

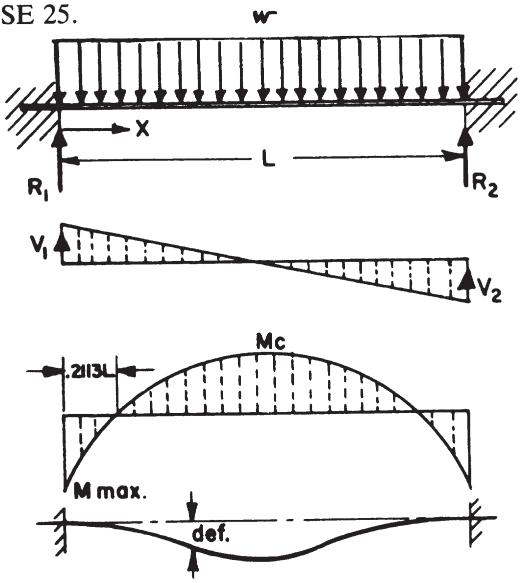
Deflection at end of overhang:

$$d_1 = -\frac{wL^3a}{24\,EI}$$

Maximum deflection between supports:

$$d_2 = \frac{5wL^4}{384\,EI}$$

CASE 25.



Uniformly distributed load, w lb/in
Total load $W = wL$

Reactions: $R_1 = R_2 = \frac{W}{2}$

Shear forces: $V_1 = +\frac{W}{2}$

$V_2 = -\frac{W}{2}$

Maximum (negative) bending moment

$$M_{\max} = -\frac{wL^2}{12} = -\frac{WL}{12}\text{, at end}$$

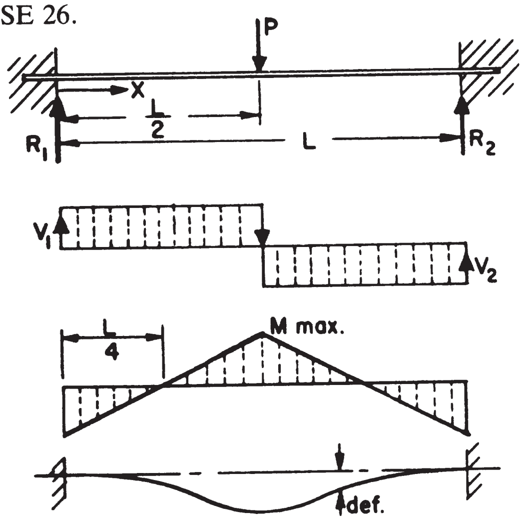
Maximum (positive) bending moment

$$M_c = \frac{wL^2}{24} = \frac{WL}{24}\text{, at center}$$

$$\text{Maximum deflection} = \frac{wL^4}{384\ EI} = \frac{WL^3}{384\ EI}\text{, at center}$$

$$\text{def.} = \frac{wx^2}{24\ EI}(L - x)^2,\quad o \le x \le L$$

CASE 26.



Concentrated load, P, at center

Reactions: $R_1 = R_2 = \frac{P}{2}$

Shear forces: $V_1 = +\frac{P}{2}$; $V_2 = -\frac{P}{2}$

Maximum bending moment

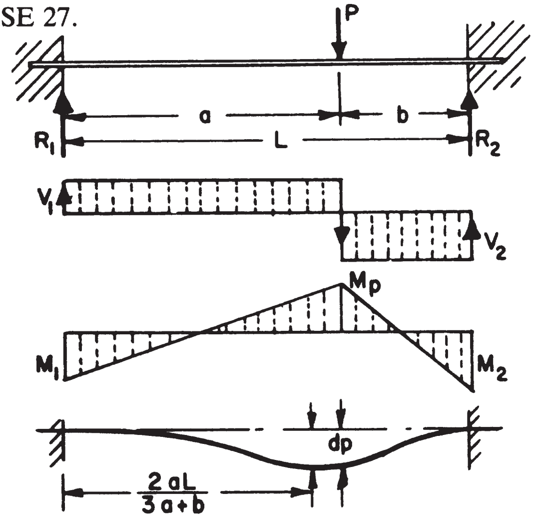
$$M_{\max} = \frac{PL}{8}\text{, at center}$$

$$M_{\max} = -\frac{PL}{8}\text{, at ends}$$

$$\text{Maximum deflection} = \frac{PL^3}{192\ EI}\text{, at center}$$

$$\text{def.} = \frac{Px^2}{48\ EI}(3L - 4x),\quad o \le x \le \frac{L}{2}$$

CASE 27.



Concentrated load, P, at any point

Reactions: $R_1 = \frac{Pb^2}{L^3}(3a + b)$

$R_2 = \frac{Pa^2}{L^3}(3b + a)$

Shear forces: $V_1 = R_1$; $V_2 = -R_2$

Bending moments:

$$M_1 = -\frac{Pab^2}{L^2}\text{, max. when } a < b$$

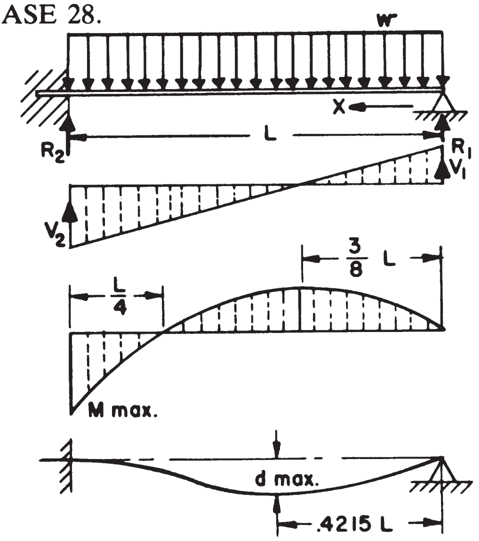
$$M_2 = -\frac{Pa^2b}{L^2}\text{, max. when } a > b$$

$$M_p = +\frac{2Pa^2b^2}{L^3}\text{, at point of load}$$

$$\text{Deflection} = \frac{Pa^3b^3}{3\ EIL^3}\text{, at point of load}$$

$$\text{Max. def.} = \frac{2Pa^3b^2}{3\ EI\ (3a + b)^2}\text{, at } x = \frac{2aL}{3a + b}\text{, for } a > b$$

CASE 28.



Uniformly distributed load, w lb/in

Total load $W = wL$

Reactions: $R_1 = \frac{3wL}{8}$, $R_2 = \frac{5wL}{8}$

Shear forces: $V_1 = +R_1$; $V_2 = -R_2$

Bending moments:

Max. negative moment $= -\frac{wL^2}{8}$, at left end

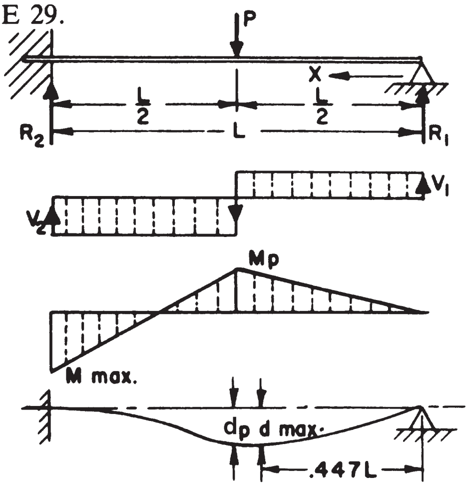
Max. positive moment $= \frac{9}{128}wL^2$, $x = \frac{3}{8}L$

$$M = \frac{3wLx}{8} - \frac{wx^2}{2},\ o \leq x \leq L$$

Maximum deflection $= \frac{wL^4}{185EI}$, $x = 0.4215\ L$

$$\text{def.} = \frac{wx}{48EI}(L^3 - 3Lx^2 + 2x^3),\ o \leq x \leq L$$

CASE 29.



Concentrated load, P, at center

Reactions: $R_1 = \frac{5}{16}P$; $R_2 = \frac{11}{16}P$

Shear forces: $V_1 = R_1$; $V_2 = -R_2$

Bending moments:

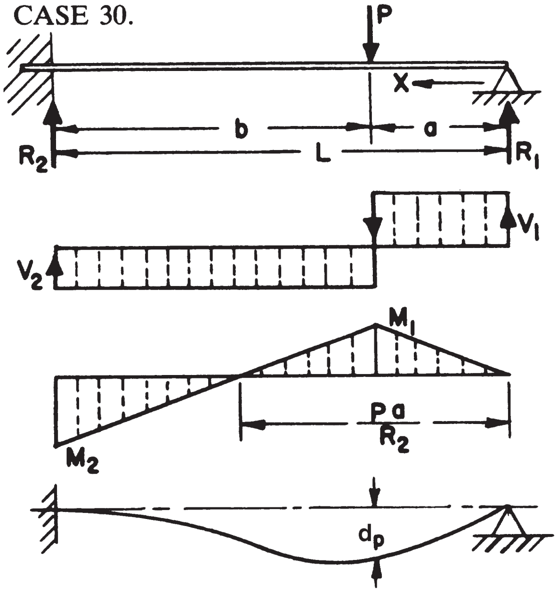
Max. negative moment $= -\frac{3\ PL}{16}$, at fixed end

Max. positive moment $= \frac{5\ PL}{32}$, at center

Maximum deflection $= 0.009317\ \frac{PL^3}{EI}$, at $x = 0.447\ L$

Deflection at center under load $= \frac{7\ PL^3}{768\ EI}$

CASE 30.



Concentrated load, P, at any point

Reactions: $R_1 = \frac{Pb^2}{2L^3}(a + 2L)$, $R_2 = \frac{Pa}{2L^3}(3L^2 - a^2)$

Shear forces: $V_1 = R_1$; $V_2 = -R_2$

Bending moments:

Max. negative moment, $M_2 = -\frac{Pab}{2L^2}(a + L)$, at fixed end

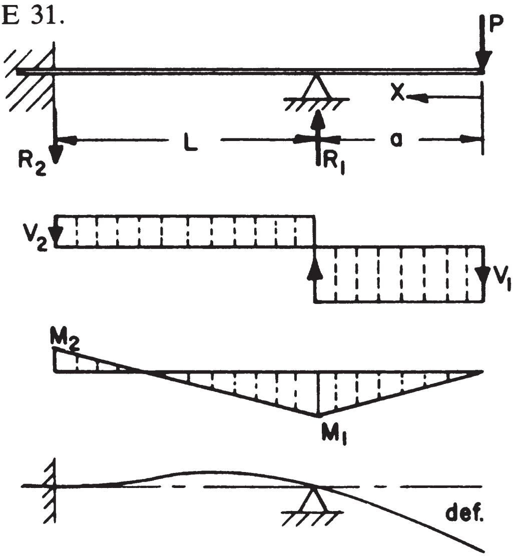
Max. positive moment, $M_1 = \frac{Pab^2}{2L^3}(a + 2L)$, at load

Deflections: $d_p = \frac{Pa^2b^3}{12\ EIL^3}(3L + a)$, at load

$$d_{\max} = \frac{Pa\ (L^2 - a^2)^3}{3\ EI\ (3L^2 - a^2)^2},\ \text{at } x = \frac{L^2 + a^2}{3L^2 - a^2}L,\ \text{when } a < 0.414\ L$$

$$d_{\max} = \frac{Pab^2}{6\ EI}\sqrt{\frac{a}{2L + a}},\ \text{at } x = L\sqrt{\frac{a}{2L + a}},\ \text{when } a > 0.414\ L$$

CASE 31.



Concentrated load, P, at end of overhang

Reactions: $R_1 = P\left(1 + \frac{3a}{2L}\right)$

$R_2 = -\frac{3\ Pa}{2\ L}$

Shear forces: $V_1 = -P$

$V_2 = \frac{3\ Pa}{2\ L}$

Bending moments:

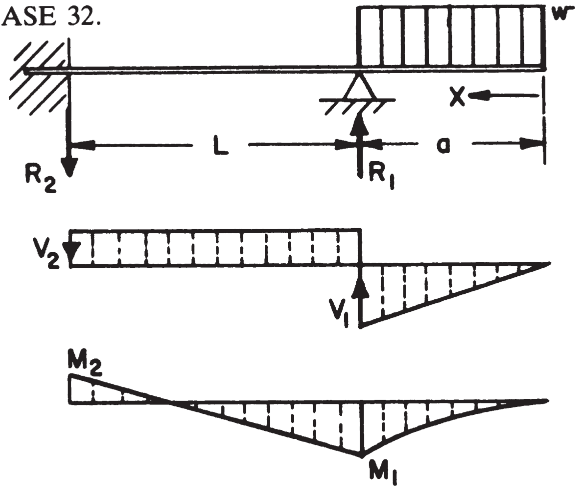
$M_1 = -Pa,\ at\ R_1$

$M_2 = \frac{Pa}{2}$, at fixed end

Deflection at end of overhang

def. $= \frac{PL^3}{EI}\left(\frac{a^2}{4\ L^2} + \frac{a^3}{3\ L^3}\right)$

CASE 32.



Distributed load, w lb/in. on overhang

Reactions: $R_1 = wa\left(1 + \frac{3a}{4\ L}\right)$

$R_2 = -\frac{3\ wa^2}{4\ L}$

Shear forces: $V_1 = -wa$

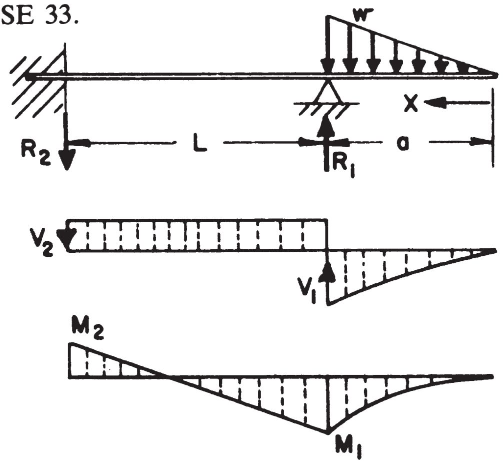
$V_2 = \frac{3\ wa^2}{4\ L}$

Bending moments:

$M_1 = -\frac{wa^2}{2},\ at\ R_1$

$M_2 = \frac{wa^2}{4}$, at fixed end

CASE 33.



Distributed triangular loading of w lb/in. maximum intensity on overhang

Reactions: $R_1 = \frac{wa}{2}\left(1 + \frac{a}{2\ L}\right)$

$R_2 = -\frac{wa^2}{4\ L}$

Shear forces: $V_1 = -\frac{wa}{2}$

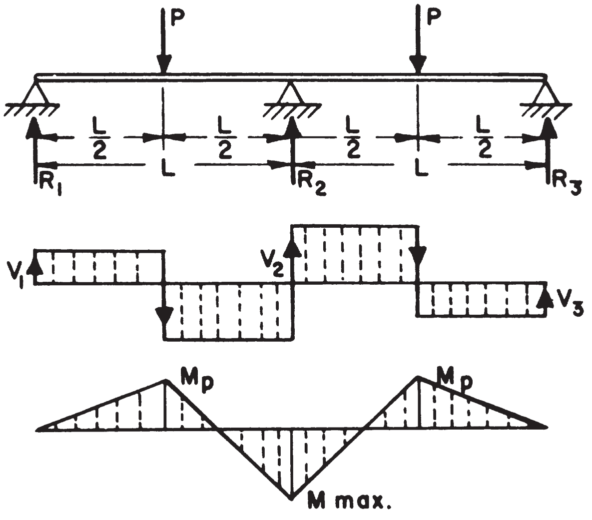
$V_2 = \frac{wa^2}{4\ L}$

Bending moments:

$M_1 = -\frac{wa^2}{6},\ at\ R_1$

$M_2 = \frac{wa^2}{12}$, at fixed end

CASE 34. Continuous beam of two equal spans—equal concentrated loads, P, at center of each span



Reactions: $R_1 = R_3 = \frac{5}{16} P$

$R_2 = 1.375 P$

Shear forces: $V_1 = - V_3 = \frac{5}{16} P$

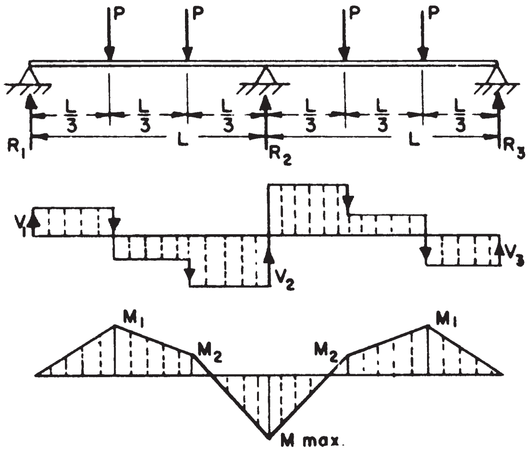
$V_2 = \pm \frac{11}{16} P$

Bending moments:

$M_{max} = - \frac{6}{32} PL$, at R_2

$M_p = \frac{5}{32} PL$, at point of load

CASE 35. Continuous beam of two equal spans—concentrated loads, P, at third points of each span



Reactions: $R_1 = R_3 = \frac{2}{3} P$

$R_2 = \frac{8}{3} P$

Shear forces: $V_1 = - V_3 = \frac{2}{3} P$

$V_2 = \pm \frac{4}{3} P$

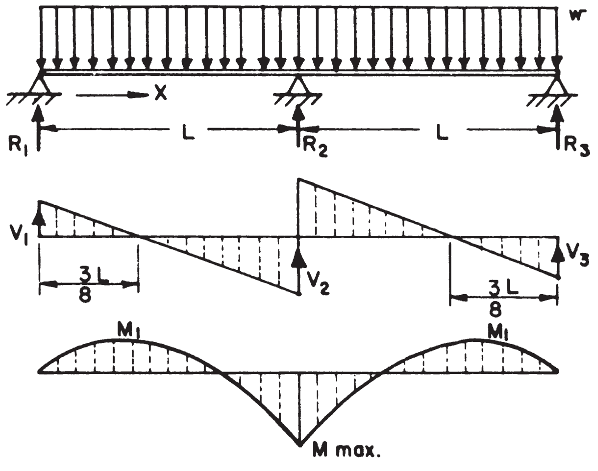
Bending moments:

$M_{max} = - \frac{1}{3} PL$, at R_2

$M_1 = \frac{2}{9} PL$

$M_2 = \frac{1}{9} PL$

CASE 36 Continuous beam of two equal spans—uniformly distributed load of w lb/in.



Reactions: $R_1 = R_3 = \frac{3}{8} wL$

$R_2 = 1.25 wL$

Shear forces:

$V_1 = - V_3 = \frac{3}{8} wL$

$V_2 = \pm \frac{5}{8} wL$

Bending moments:

$M_{max} = - \frac{1}{8} wL^2$

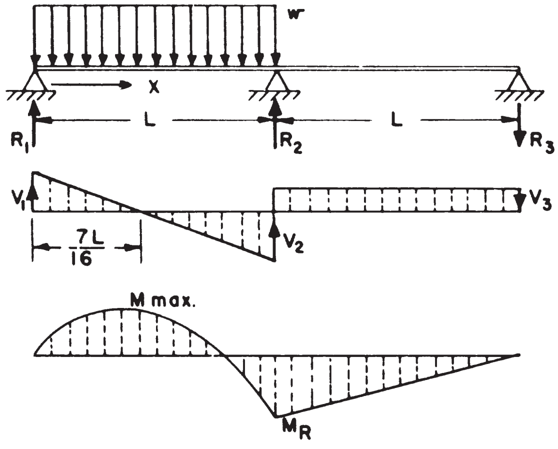
$M_1 = \frac{9}{128} wL^2$

Maximum deflection $= 0.00541 \frac{wL^4}{EI}$

at $x = 0.4215 L$

Def. $= \frac{w}{48 EI}(L^3x - 3 Lx^3 + 2x^4)$, $o \leq x \leq L$

CASE 37. Continuous beam of two equal spans—uniformly distributed load of w lb/in. on one span



Reactions: $R_1 = \frac{7}{16} wL,\ R_2 = \frac{5}{8} wL,\ R_3 = -\frac{1}{16} wL$

Shear forces: $V_1 = \frac{7}{16} wL,\ V_2 = -\frac{9}{16} wL,\ V_3 = \frac{1}{16} wL$

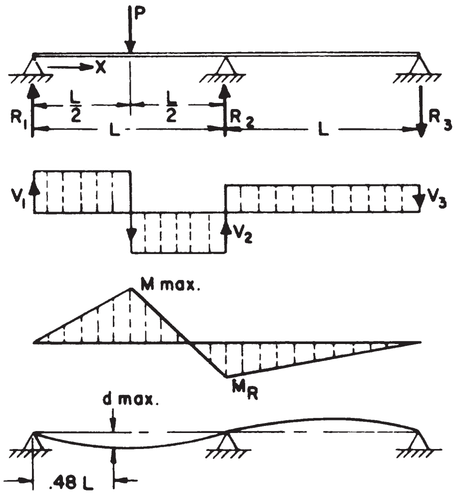
Bending moments:

$$M_{\max} = \frac{49}{512} wL^2, \text{ at } x = \frac{7}{16} L$$

$$M_R = -\frac{1}{16} wL^2, \text{ at } R_2$$

$$M = \frac{wx}{16} (7L - 8x),\ o \le x \le L$$

CASE 38. Continuous beam of two equal spans—concentrated load, P, at center of one span.



Reactions: $R_1 = \frac{13}{32} P,\ R_2 = \frac{11}{16} P,\ R_3 = -\frac{3}{32} P$

Shear forces: $V_1 = \frac{13}{32} P,\ V_2 = -\frac{19}{32} P,\ V_3 = \frac{3}{32} P$

Bending moments:

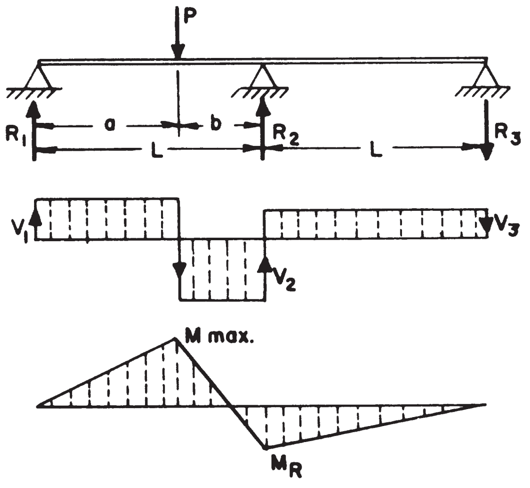
$$M_{\max} = \frac{13}{64} PL, \text{ at point of load}$$

$$M_R = -\frac{3}{32} PL, \text{ at support } R_2$$

Maximum deflection:

$$d_{\max} = \frac{0.96\ PL^3}{64\ EI}, \text{ at } x = 0.48L$$

CASE 39. Continuous beam of two equal spans—concentrated load, P, at any point on one span.



Reactions: $R_1 = \frac{Pb}{4L^3} [4L^2 - a(L + a)]$

$$R_2 = \frac{Pa}{2L^3} [2L^2 + b(L + a)]$$

$$R_3 = -\frac{Pab}{4L^3} (L + a)$$

Shear forces: $V_1 = \frac{Pb}{4L^3} [4L^2 - a(L + a)]$

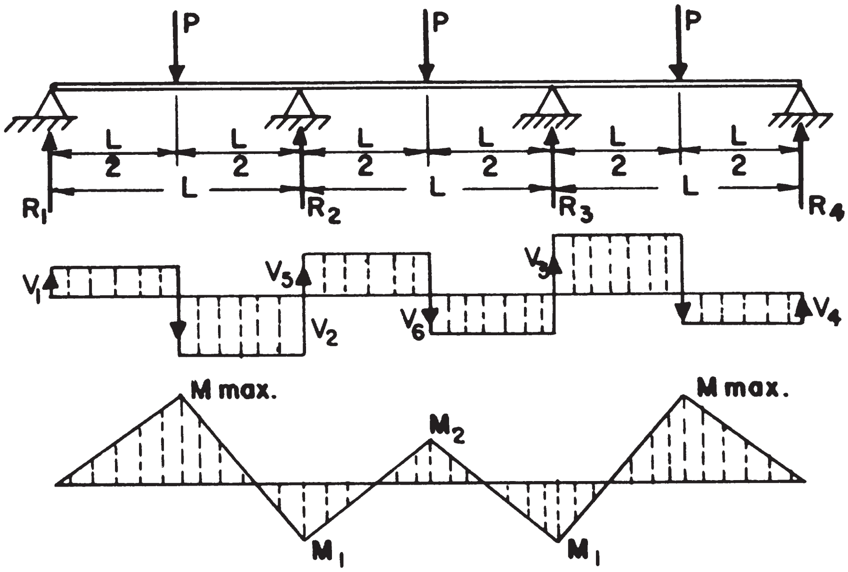
$$V_2 = -\frac{Pa}{4L^3} [4L^2 + b(L + a)]$$

$$V_3 = \frac{Pab}{4L^3} (L + a)$$

Bending moments: $M_{\max} = \frac{Pab}{4L^3} [4L^2 - a(L + a)]$

$$M_R = -\frac{Pab}{4L^2} (L + a)$$

CASE 40. Continuous beam of three equal spans—concentrated load, *P*, at center of each span



Reactions: $R_1 = R_4 = \frac{7}{20} P$

$R_2 = R_3 = \frac{23}{20} P$

Shear forces:

$V_1 = -V_4 = \frac{7}{20} P$

$V_3 = -V_2 = \frac{13}{20} P$

$V_5 = -V_6 = \frac{P}{2}$

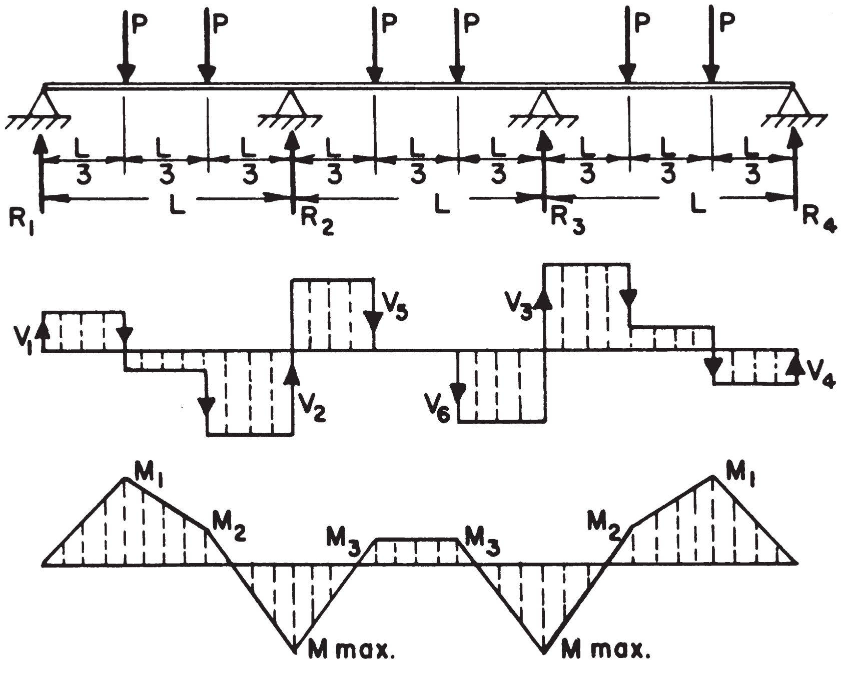
Bending moments:

$M_{\max} = \frac{7}{40} PL$

$M_1 = -\frac{3}{20} PL$

$M_2 = \frac{1}{10} PL$

CASE 41. Continuous beam of three equal spans—concentrated loads, *P*, at third points of each span



Reactions:

$R_1 = R_4 = \frac{11}{15} P$

$R_2 = R_3 = \frac{34}{15} P$

Shear forces:

$V_1 = -V_4 = \frac{11}{15} P$

$V_3 = -V_2 = \frac{19}{15} P$

$V_5 = -V_6 = P$

Bending moments:

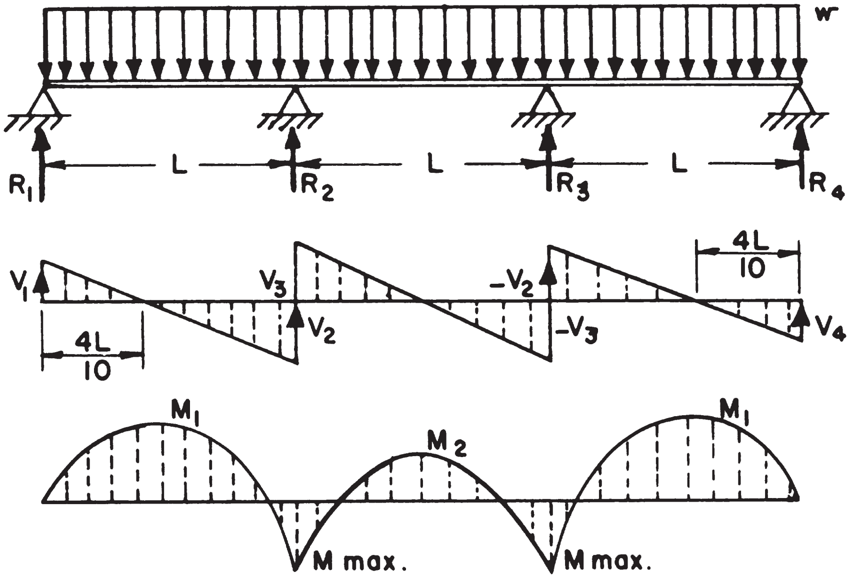
$M_{\max} = -\frac{12}{45} PL$

$M_1 = \frac{11}{45} PL$

$M_2 = \frac{7}{45} PL$

$M_3 = \frac{3}{45} PL$

CASE 42. Continuous beam of three equal spans—uniformly distributed load



Loading: w lb/in

Reactions:

$$R_1 = R_4 = \frac{4wL}{10}$$

$$R_2 = R_3 = \frac{11wL}{10}$$

Shear forces:

$$V_1 = -V_4 = \frac{4wL}{10}$$

$$V_2 = -\frac{6wL}{10}$$

$$V_3 = \frac{5wL}{10}$$

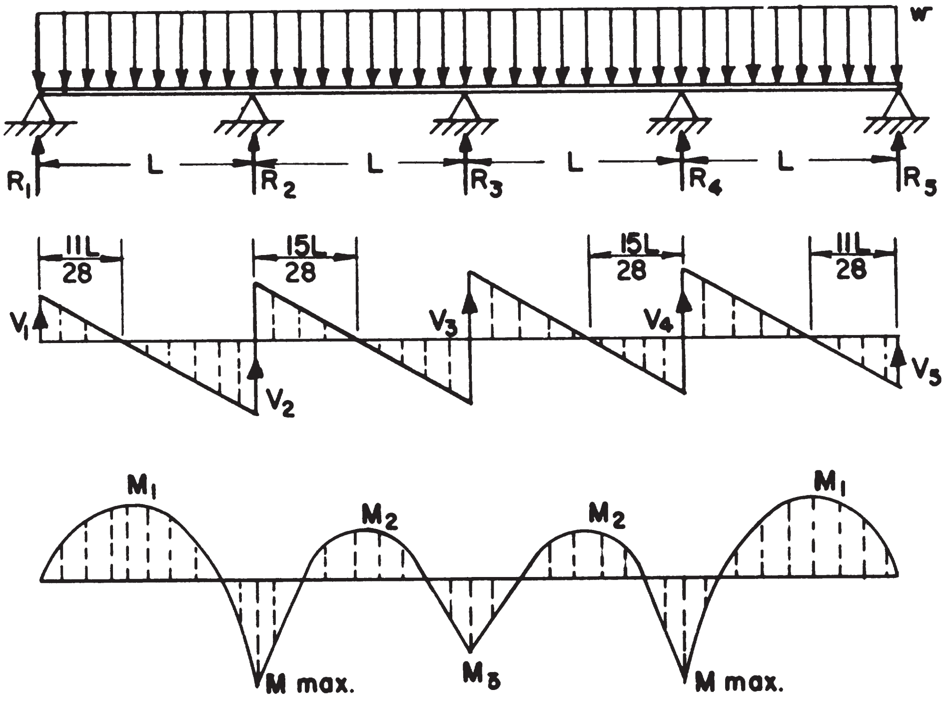
Bending moments:

$$M_{\max} = -\frac{wL^2}{10}, \text{ at } R_2 \text{ and } R_3$$

$$M_1 = \frac{4wL^2}{50}, \text{ at } 0.4L \text{ from } R_1 \text{ and } R_4$$

$$M_2 = \frac{wL^2}{40}, \text{ at center}$$

CASE 43. Continuous beam of four equal spans—uniformly distributed load



Loading: w lb/in

Reactions: $R_1 = R_5 = \frac{11wL}{28}$

$$R_2 = R_4 = \frac{32wL}{28}$$

$$R_3 = \frac{26wL}{28}$$

Shear forces:

$$V_1 = -V_5 = \frac{11wL}{28}$$

$$V_4 = -V_2 = \frac{17wL}{28}$$

$$V_3 = \frac{13wL}{28}$$

Bending moments:

$$M_{\max} = -\frac{168wL^2}{1568}, \text{ at } R_2 \text{ and } R_4$$

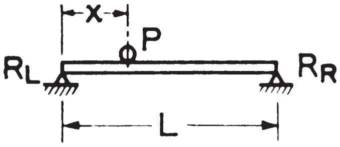
$$M_1 = \frac{121wL^2}{1568}$$

$$M_2 = \frac{57wL^2}{1568}$$

$$M_3 = -\frac{112wL^2}{1568}$$

CASE 44. **SIMPLE BEAM**

One Concentrated Moving Load

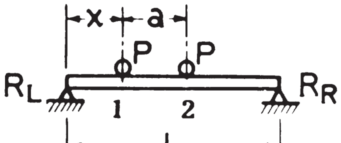


R_L max $=$ V_L max (at $x = 0$) $= P$

$$M \max\left(\text{at point of load, when } x = \frac{L}{2}\right) = \frac{PL}{4}$$

CASE 45. **SIMPLE BEAM**

Two Equal Concentrated Moving Loads

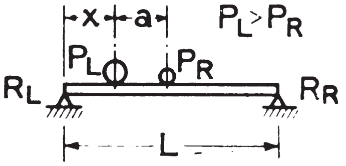


R_L max $=$ V_L max (at $x = 0$) $= P\left(2 - \frac{a}{L}\right)$

$$M \max \begin{cases} \left[\begin{array}{l} \text{when } a < (2 - \sqrt{2})\,L = 0.586L \\ \text{under load 1 at } x = \frac{1}{2}\left(L - \frac{a}{2}\right) \end{array}\right] = \frac{P}{2L}\left(L - \frac{a}{2}\right)^2 \\ \left[\begin{array}{c} \text{when } a > (2 - \sqrt{2})\,L = 0.586L \\ \text{with one load at center of span} \\ \text{(other load is then off span)} \end{array}\right] = \frac{PL}{4} \end{cases}$$

CASE 46. **SIMPLE BEAM**

Two Unequal Concentrated Moving Loads

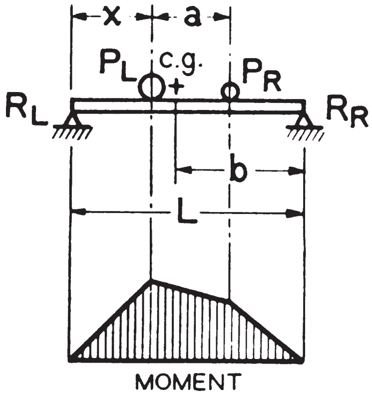


R_L max $=$ V_L max (at $x = 0$) $= P_L + P_R\frac{L - a}{L}$

$$M \max \begin{cases} \left[\text{under } P_L\text{, at x} = \frac{1}{2}\left(L - \frac{P_R a}{P_L + P_R}\right)\right] = (P_L + P_R)\frac{x^2}{L} \\ \left[\begin{array}{l} M \text{ max may occur with larger load at} \\ \text{center of span and other load off span} \end{array}\right] = \frac{P_L L}{4} \end{cases}$$

CASE 47.

GENERAL RULES FOR SIMPLE BEAMS CARRYING CONCENTRATED MOVING LOADS



Maximum shear due to moving concentrated loads occurs at one support when one of the loads is at that support. With several moving loads, the point of maximum shear must be determined by trial. Maximum bending moment produced by moving concentrated loads occurs under one of the loads when that load is as far from one support as the center of gravity of all the moving loads on the beam is from the other support.

In the diagram, maximum bending moment occurs under load P_L when $x = b$. It should also be noted that this condition occurs when the center line of the span is midway between the center of gravity of the loads and the nearest concentrated load.

Aluminum Design Manual

PART VII

Illustrative Examples

VII
Illustrative Examples

This part of the Design Manual illustrates the use of the *Specification for Aluminum Structures,* Part I of the Design Manual. Terms and symbols used in Part VII are consistent with those used in the *Specification for Aluminum Structures,* which should be consulted for their definitions. References in Part VII to section and table numbers are to the section and table numbers in the *Specification for Aluminum Structures.*

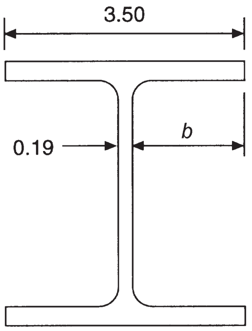
TABLE OF CONTENTS

CORRELATION OF SPECIFICATION SECTIONS AND ILLUSTRATIVE EXAMPLES

Type of Stress	Type of Member and Element	Section No.*	Main Examples	Other Examples
ELEMENTS IN UNIFORM COMPRESSION	Flat elements supported on one edge	B.5.4.1	10, 11, 21	3, 9, 13 16, 22, 23, 26
	Flat elements supported on both edges	B.5.4.2	12, 22	4, 9, 11, 20, 24, 29
	Curved elements supported on both edges	B.5.4.5	14	12
ELEMENTS IN FLEXURE	Flat elements supported on tension edge, compression edge free	B.5.5.2	23	
	Flat elements supported on both edges	B.5.5.1	24	3, 16, 20, 21, 22, 23
	Flat elements supported on both edges and with a longitudinal stiffener	B.5.5.3	25	
TENSION, axial	All tension members	D.2	1	2
COMPRESSION, axial	All columns	E.3	9	10, 11, 12, 14
FLEXURE	Open shapes	F.2	15, 16, 17	3, 21, 22, 23, 26, 28
	Round tubes	F.6	18	5
	Rods	F.7	19	6
	Closed shapes	F.3	20	4
SHEAR	Flat elements supported on both edges	G.2	26	3, 4, 15, 20, 21, 22, 23
BEARING	On rivets	J.4.7	7	
	On flat surfaces and pins	J.7	8	

*The section number refers to the type of stress and member used and corresponds to the number in the *Specification for Aluminum Structures.*

In the following examples, widths of elements are conservatively calculated ignoring the effect of corner fillets. For example, in example 3 the flange element width *b,* used to calculate the allowable stress in the flange of I 5 × 3.70, is calculated from the face of the web as shown in Figure i



$$b = \frac{3.50 - 0.19}{2} = 1.65$$

Figure i

Example 1
ROD IN AXIAL TENSION
Illustrating Section D.2

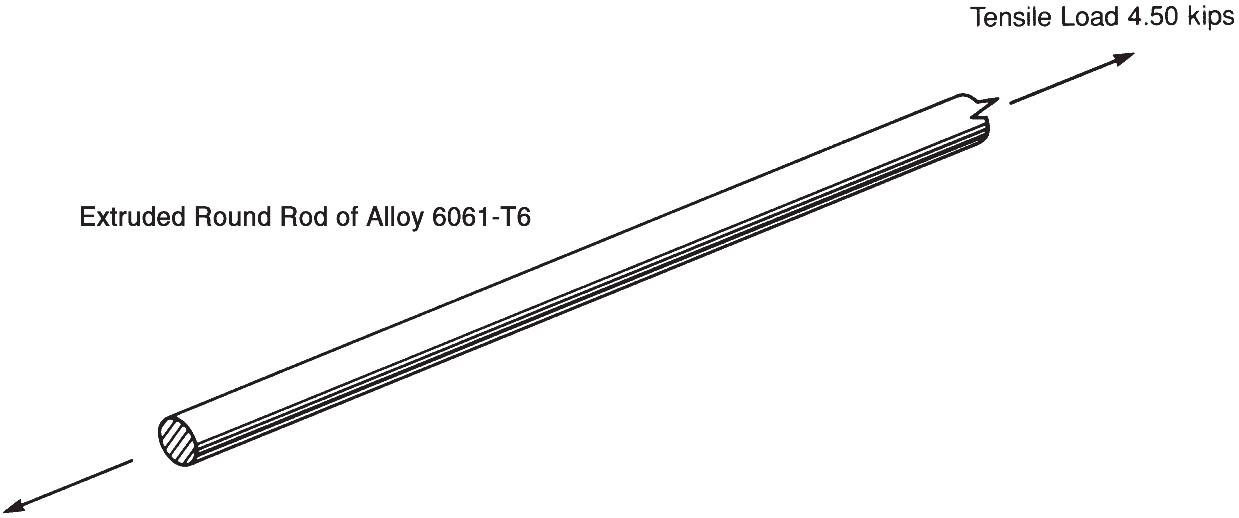


Figure 1

GIVEN:

1. Tensile load: 4.50 k (4,500 lb).
2. Alloy: 6061-T6.
3. Structure type: building.

REQUIRED:

Diameter of smallest standard rod that will safely resist the load.

SOLUTION:

From Part VI Table 2-19, Section D.2: Allowable tensile stress: The net section allowable stress is less than the gross section allowable stress and the net section is less than the gross section, so only the net section needs to be considered.

$F/\Omega = 19.5$ ksi on the net section

Given load $P = 4.50$ k

$$\text{Required area } A = \frac{P}{F/\Omega} = \frac{4.50 \text{ k}}{19.5 \text{ k/in}^2} = 0.231 \text{ in}^2$$

From Part V, Table 28, the required diameter for $A = 0.231 \text{ in}^2$:

$$\frac{\pi D^2}{4} = 0.231 \text{ in}^2$$

$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4(0.231)}{\pi}} = 0.542 \text{ in.}$$

A $^3/_4$ in. diameter rod has a minor diameter of 0.642 in. at the net section (at the threads), so use $D = {}^3/_4$ in.

NOTE: Long slender members have little resistance to lateral loads. Therefore, tension members with large slenderness ratios L/r should be avoided unless such members can also resist vibration and lateral loads such as wind, dead load, and the weight of workmen and equipment.

Example 2
RECTANGULAR STRAP IN AXIAL TENSION
Illustrating Section D.2

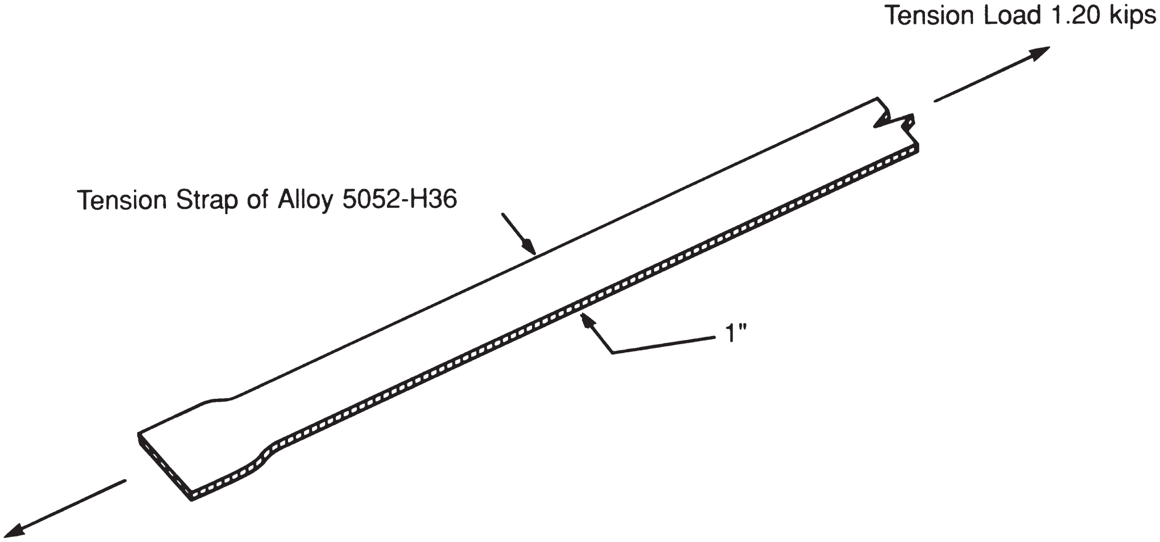


Figure 2

GIVEN:

1. Tensile load: 1.20 k (1,200 lb).
2. Alloy: 5052-H36.
3. Structure type: building.

REQUIRED:

Thickness of a 1 in. wide strap which will safely resist the load. Assume that the ends of the strap are connected so that the net section is sufficiently large that it does not govern the tensile strength of the strap.

SOLUTION:

From Section D.2, the allowable tensile strength for yielding in the gross section is

$$P_n = F_{ty} A_g / \Omega_t = 1.20 \text{ k}$$

Reading F_{ty} from Table A.3.4 as 29 ksi, the required gross area is

$$A_g = P_n \Omega_t / F_{ty} = (1.20 \text{ k})(1.65)/(29 \text{ k/in}^2) = 0.0683 \text{ in}^2$$

The required thickness for 1.00 in. width is

$$t = 0.0683 \text{ in}^2/(1.00 \text{ in.}) = 0.0683 \text{ in.}$$

From Part V, Table 3, the minimum standard thickness ≥ 0.0683 in. is $t = 0.071$ in.

Example 3
I-BEAM IN BENDING
Illustrating Sections F.2, F.8, G.2

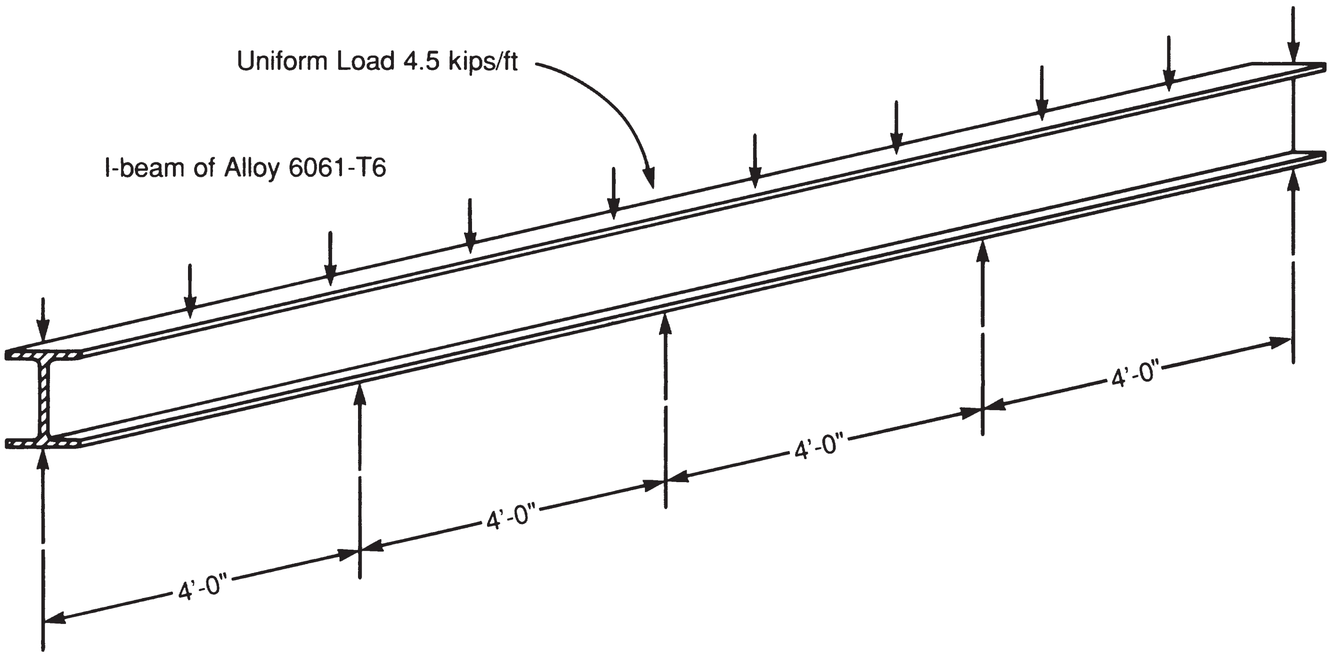


Figure 3

GIVEN:

1. Uniform load of 4.50 k/ft (4,500 lb/ft) including dead load.
2. Beam length 16 ft with continuous lateral support.
3. Vertical support spacing 4 ft o.c. (first support at end of beam).
4. Alloy: 6061-T6.
5. Structure type: building.

REQUIRED:

Size of lightest Aluminum Association standard I-beam that will safely support the load.

SOLUTION:

From Part VI Beam Formulas Case 43 continuous beam of four equal spans, uniformly distributed load:

Load $w = (4.50 \text{ k/ft})(\text{ft}/12 \text{ in.}) = 0.375 \text{ k/in.}$

The maximum bending moment is

$$M = -168\, wL^2/1568 = -168(0.375 \text{ k/in.})(48 \text{ in})^2/1568 = -92.6 \text{ in-k}$$

The negative sign for the bending moment M indicates that the top flange of the beam is in tension. The point of maximum stress is at the first interior support.

Section F.2, open shapes, requires that for open shapes not subject to lateral-torsional buckling, the nominal flexural strength be determined using Section F.8.

For tension, from Part VI Table 2-19, conservatively using F.8.1.1 (for the flanges which are in uniform tension) since it gives a lesser strength than F.8.1.2 (for the web, which is in flexure), the allowable tensile bending stress is

$F/\Omega = 19.5$ ksi

Required section modulus S:

$S = M/(F/\Omega) = (92.6 \text{ in-k})/(19.5 \text{ k/in}^2) = 4.75 \text{ in}^3$

From Part V, Table 8

Select trial I-beam I 5 × 3.70
$S_x = 5.58 \text{ in}^3$

Now check the beam for compression according to Section F.8.2.

a) The flange is in uniform compression, so according to Section F.8.2.1, the strength is given in Section B.5.4. Section B.5.4.1 addresses flat elements supported on one edge; from Part VI, Table 2-19

$b/t = (3.50 - 0.19)/[(2)(0.32)] = 5.2 < 6.7 = S_1$, so
$F/\Omega = 21.2$ ksi

b) Section F.8.2.2 refers to Section B.5.5 for the strength of the web in flexure. Section B.5.5.1 addresses flat elements supported on both edges. Since the beam is symmetric about the bending axis, $c_c = -c_o$, and $m = 0.65$.

$b/t = (5.00 - 2(0.32))/0.19 = 22.9 < S_1, = 49.3$,
so $F/\Omega = 27.6$ ksi

The allowable bending stress is therefore governed by tension ($F/\Omega = 19.5$ ksi)

Web shear is addressed by Section G.2, flat webs supported on both edges.

$b/t = 22.9 < 35.3 = S_1$, so $F_s/\Omega = 12.7$ ksi, allowable shear stress

From Part VI Beam Formulas Case 43, continuous beam of four equal spans.

$V = 17\ wL/28 = 17(0.375\text{ k/in})(48\text{ in})/28 = 10.9$ k, maximum web shear

The required web area is $A = V/(F_s/\Omega) = (10.9\text{ k})/(12.7\text{ k/in}^2) = 0.86\text{ in}^2$

(The above is an approximate method. See example 26.) For I 5 × 3.70

$A_w = dt_w = (5.00)\ 0.19$
$= 0.95\text{ in}^2 > 0.86\text{ in}^2$

The I 5 × 3.70 is therefore the lightest satisfactory beam.

NOTES: The building code should be checked to see if analysis for other loading conditions (such as alternate span loading) is required in addition to the load addressed above. Generally, the use of the formula $M = \pm\ wL^2/8$ satisfies all building code requirements for uniformly loaded beams supported on both ends.

If holes will be drilled in the flange at or near points of high tensile stress, it may be necessary to use a larger beam. This may be determined by multiplying the computed flange stress at the section under consideration by the ratio of the gross area of the flange to the net area of the flange and comparing the result with the allowable stress.

Web crippling at supports should be checked; see Example 4.

Example 4
SQUARE TUBE IN BENDING
Illustrating Sections F.8.1, F.8.2, G.2, and J.8.1

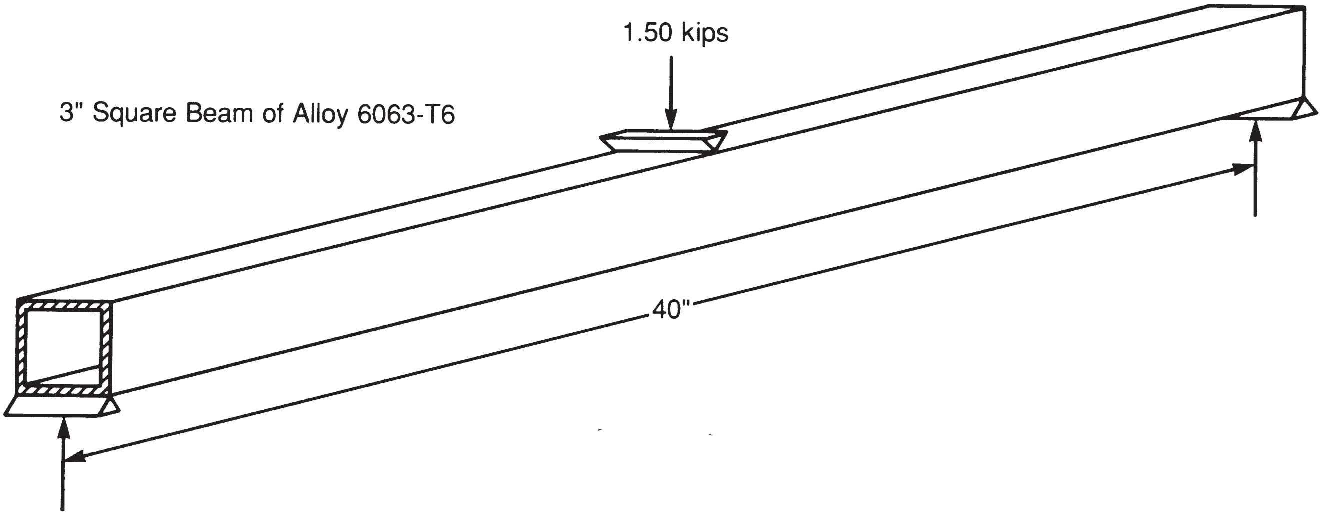


Figure 4

GIVEN:

1. Concentrated load of 1.50 k (1,500 lb) including dead load, applied at mid span.
2. Span 40 in., simply supported
3. Alloy: 6063-T6
4. Structure type: building

REQUIRED:

Thickness of a standard 3 in. square tube that will safely support the load.

SOLUTION:

From Part VI Beam Formulas Case 1, a simply supported beam with a concentrated load P at the center, the maximum bending moment = $M = PL/4 = (1.5\text{ k})(40\text{ in.})/4 = 15.0$ in-k

A square tube is not subject to lateral-torsional buckling, so Section F.3, Tubular Shapes, requires that the nominal flexural strength be determined from Section F.8.

For tensile bending, the allowable tensile bending stress can be conservatively determined as the lesser of F.8.1.1 (for the flanges) and F.8.1.2 (for the webs), which is F.8.1.1

From Part VI, Design Aids, Table 2-21, $F/\Omega = 15.2$ ksi

Required section modulus S:

$S = M/F = (15.0\text{ in-k})/(15.2\text{ k/in}^2) = 0.99\text{ in}^3$

Part V, Table 23, shows that a 3 × 3 × 0.125 square tube has a section modulus $S = 1.32\text{ in}^3$, which exceeds the required section modulus for tension, so select this as a trial size.

For compression bending in a square tube, Section F.8.2.1, Elements in Uniform Compression, governs; this section refers to Section B.5.4. From Part VI, Table 2-21, Section B.5.4.2, flat elements supported on both edges:

$b/t = (3\text{-}2(0.125))/0.125 = 22 \le S_1 = 22.8$

$F_b/\Omega = 15.2$ ksi; bending stress is satisfactory.

For shear in the web, Part VI Beam Formulas Case 1 gives

$V = P/2 = (1.5\text{k})/2 = 0.75$ k

From Part VI, Table 2-21, Section G.2 gives the allowable shear stress.

$b/t = 22.0 < 38.7 = S_1$, so $F_s/\Omega = 9.1$ ksi

Area of webs, $A = 2 \times 0.125 \times (3.00 - 2 \times 0.125) = 0.687\text{ in}^2$

Approximate web shear stress

$f_s = V/A = (0.75\text{ k})/(0.687\text{ in}^2) = 1.1\text{ k/in}^2 < 9.1\text{ k/in}^2$

(See example 26 for a discussion of the accuracy of this method.)

Use 3 in. × 0.125 in. hollow square tubing.

NOTES: A lighter tube in 6061-T6 alloy would be satisfactory structurally; however, for architectural uses, 6063-T6 may be preferred because of its superior finishing characteristics.

The supports and load point of Figure 4 are shown as sharp, a condition seldom used in actual practice but used here to define the span length more clearly. In an actual installation, the forces on the beam will be distributed over a distance *N,* which must be large enough to prevent local crippling of the webs.

Section J.8.1 addresses Crippling of Flat Webs. From Table A.3.4, $F_{cy} = 25$ ksi, $E = 10{,}100$ ksi

$R_i = 0$ for extruded shapes

$t = 0.125$ in., $\theta = 90°$, Try $N = 0.10$ in.

The allowable reaction R_n/Ω for concentrated forces applied at a distance from the member end that is less than the member depth divided by 2 is

$R_n/\Omega = (1.2C_{wa})(N + C_{w2})/[(C_{wb})(\Omega)]$

where

$$\begin{aligned} C_{wa} &= t^2 \sin\theta(0.46F_{cy} + 0.02\sqrt{EF_{cy}}) \\ &= (0.125)^2 \sin 90° \ (0.46\ (25) + 0.02\sqrt{(10{,}000)(25)}) \\ &= 0.337 \text{ k} \end{aligned}$$

$C_{wb} = C_{w3} + R_i\ (1 - \cos\theta)$

$C_{w3} = 0.4$ in.

$C_{wb} = 0.4 + 0(1 - \cos 90) = 0.4$ in.

$C_{w2} = 1.3$ in.

So

$R_n/\Omega = (1.2)(0.337)(0.10 + 1.3)/[(0.4)(1.95)]$

$R_n/\Omega = 0.726$ k allowable, per web.

For two webs the end reaction per web is

$V/2 = 0.75/2 = 0.375$ k

0.375 k < 0.726 k; therefore a bearing length of 0.10 in. is satisfactory

Example 5
PIPE IN BENDING
Illustrating Sections F.6.1, F.6.2

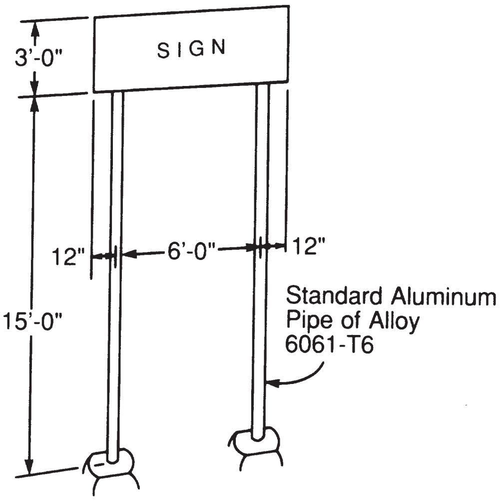


Figure 5

GIVEN:

1. Wind load 25 lb/ft^2 on 3 ft high signboard, the bottom of which is 15 ft above the base of the supporting pipes, and 20.1 lb/ft^2 on the supports. See Figure 5.
2. Support: Schedule 40 standard pipes spaced as shown in Figure 5.
3. Alloy: 6061-T6
4. Base: Welded with 5356 filler
5. Structure type: building

REQUIRED:

Size of standard pipe to safely resist the load

SOLUTION:

Table A.3.5 gives the properties for welded 6061-T6 as:

$F_{tu} = 24$ ksi, $F_{ty} = 15$ ksi, $F_{cy} = 15$ ksi

From Section F.6.1 the allowable bending stress in the pipe for the limit states of yielding and rupture at the welded base is the lesser of

$1.17F_{cy}/\Omega = (1.17)(15 \text{ ksi})/1.65 = 10.6$ ksi and
$1.17F_{ty}/\Omega = (1.17)(15 \text{ ksi})/1.65 = 10.6$ ksi and
$1.24F_{tu}/\Omega = (1.24)(24 \text{ ksi})/1.95 = 15.3$ ksi; 10.6 ksi controls.

From Part VI, Beam Formulas Case 14, concentrated load, *P*, at free end of cantilever beam: The load from the sign is not actually a concentrated load as in the beam diagram, however, the moment at the base is correctly determined using the resultant of the sign force acting at the center of the sign.

Load = 25 lb/ft^2 = 0.025 k/ft^2
$P = 0.025 \times 3.00 \times 4.00 = 0.30$ k
$L = (15 + 0.5 \times 3) \times 12 = 198$ in.
$M_1 = PL = 0.30 \times 198 = 59.4$ in-k

This is the portion of the total load moment due to wind load on the sign and must be corrected later when the pipe size is known for the additional moment caused by wind load on the pipe.

Trial section modulus

$$S = \frac{M_1}{F/\Omega} = \frac{59.4}{10.6} = 5.60 \text{ in}^3$$

From Part V, Table 26, a trial pipe size is obtained.

6 in. Schedule 40, $S = 8.50$ in^3, OD = 6.63 in., $t = 0.280$ in.

Adding the moment due to wind load on the pipe, from Case 16, cantilever beams, uniformly distributed load of *w* k/in.

$w = (0.0201)(6.63)/(144) = 0.000925$ k/in.

$M_2 = wL^2/2 = (0.000925)[(15)(12)]^2/2 = 15.0$ in-k

Total moment $M = M_1 + M_2 = 59.4 + 15.0 = 74.4$ in-k

$$f = \frac{M}{S} = \frac{74.4}{8.50} = 8.8 \text{ ksi} < 10.6 \text{ ksi}$$

Size selected is satisfactory for yielding and rupture. Section F.6.2 addresses local buckling in round tubes.

$$R_b/t = \frac{(6.63 - 0.280)/2}{0.280} = 11.3$$

Taking buckling constants from Part VI, Table 1-2, for welded 6061-T6

$$S_1 = \left(\frac{B_{tb} - 1.17F_{cy}}{D_{tb}}\right)^2 = \left(\frac{29.2 - (1.17)(15)}{1.538}\right)^2 = 57 > 11.3$$

so $F_b/\Omega = B_{tb} - D_{tb}\sqrt{R_b/t} = 29.2 - 1.538\sqrt{11.3} = 24.0$ ksi; (24.0 ksi)/1.65 = 14.5 ksi > 8.8 ksi; so the size is satisfactory. Use 6 in. Schedule 40 pipe.

NOTE: The axial stress in the supports due to dead load is assumed to be negligible in comparison to the reserve strength available; however, if the sign is very heavy, the effect should be considered.

Example 6
PLATE IN BENDING
Illustrating Section F.4.1

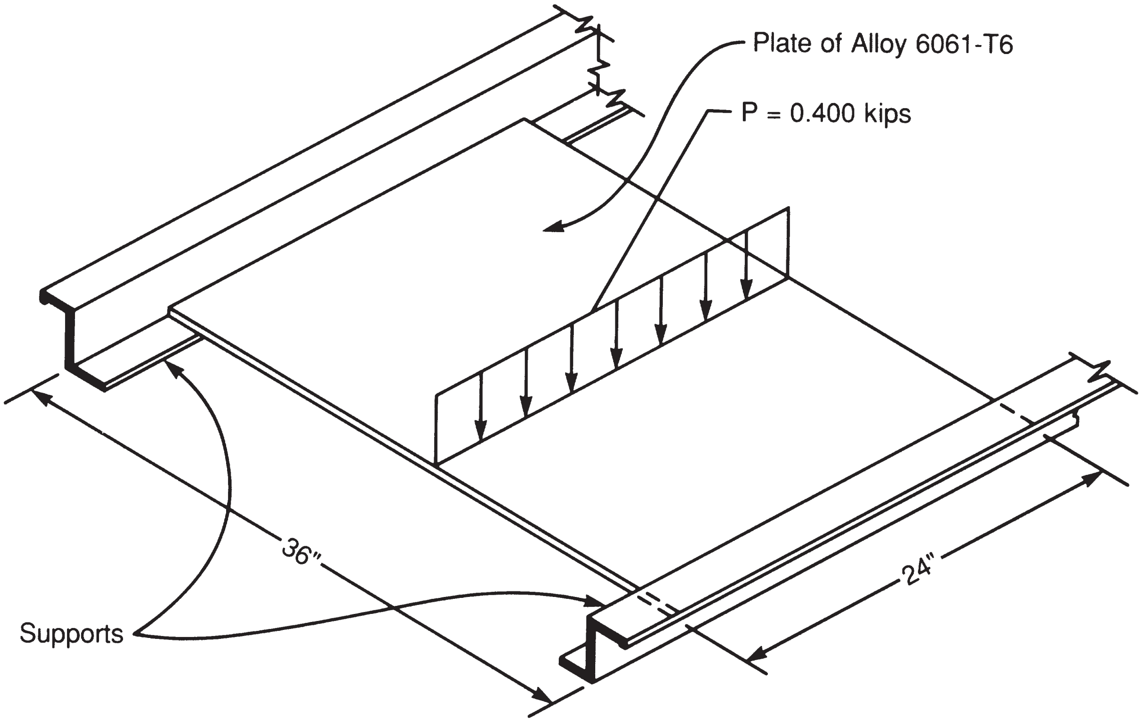


Figure 6

GIVEN:

1. Load 0.400 k (400 lb), along a line at the center of a plate.
2. Plate: 24 in. wide, spanning 36 in.
3. Alloy: 6061-T6
4. Structure type: building

REQUIRED:

Minimum standard thickness to support the load safely without deflecting more than ⅜ in.

SOLUTION:

From Part VI Table 2-18, for elements in flexure
Section F.4.1: Allowable tensile stress

$$F/\Omega = 27.6 \text{ ksi}$$

Section F.4.1. Allowable compressive stress

$$F_b/\Omega = 27.6 \text{ ksi}$$

From Part VI, Beam Formulas Case 1, simply supported beam, concentrated load P at center

$$M = PL/4 = (0.4)(36)/4 = 3.60 \text{ in-k}$$

The required section modulus is

$$S = M/(F/\Omega) = (3.6)/27.6 = 0.130 \text{ in}^3$$

From Part VI, Table 28, the section modulus of rectangle is

$$S = bd^2/6 \text{ where } b = 24 \text{ in. and } d = t_1$$

Solving for t_1

$$t_1 = \sqrt{\frac{6S}{b}} = \sqrt{\frac{6(0.130)}{24}} = 0.18 \text{ in.}$$

Deflection
From Part VI Beam Formulas Case 1

$$Deflection = PL^3/(48\ EI)$$

A correction is required for plates because individual fibers are restricted in the way they can change shape in the direction perpendicular to the stress. They can change in vertical dimension but not in horizontal dimension. The correction is:

$$\text{Deflection} = \Delta = \frac{PL^3(1-\nu^2)}{48EI}$$

where ν = Poisson's ratio, given in Table A.3.1 as 0.33.

From Part V Table 28 the moment of inertia for a rectangle is

$$I = \frac{bt_2^3}{12}$$

Section L.3 requires that bending deflections be determined using the compression modulus of elasticity from Table A.3.4, in which $E = 10{,}100$ ksi

Combining the equations for I and Δ,

$$t_2 = \sqrt[3]{\frac{PL^3(1-\nu^2)}{4bE\Delta}} = \sqrt[3]{\frac{(0.4)36^3(1-0.33^2)}{4(24)(10{,}100)(0.375)}} =$$

= 0.36 in., based on limiting deflection to 0.375 in..

Since $t_2 > t_1$ deflection controls; use $^3/_8$ in. thick plate.

NOTES: The rails supporting the plate are assumed to have been checked structurally to see that they will safely support the load. They should be fastened to the plate at intervals to prevent spreading.

The loading and deflection limits in this problem differ from those for Part VI Table 4-3.

Example 7
BEARING ON RIVETS
Illustrating Section J.4

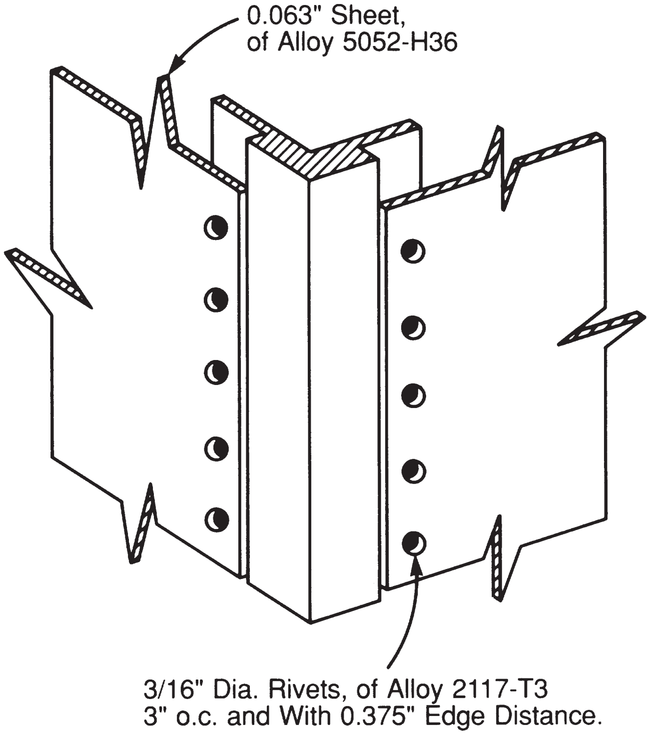


Figure 7

GIVEN:

1. Rivets: $^3\!/_{16}$ in. diameter, cold-driven, 2117-T4 before driving, spaced 3 in. on centers, edge distance 0.375 in., in a 0.191 in. hole.
2. Sheet: 0.063 in., 5052-H36 alloy.
3. Corner post extrusion considerably thicker than the sheet and with equivalent unit bearing strength.
4. Load: 0.090 k/in. shear (90 lb/in.).
5. Structure type: building

REQUIRED:

Check the strength of the connection for compliance with the Specification for Aluminum Structures.

SOLUTION:

The rivet spacing meets the requirements of Section J.4.3 because it exceeds 3 times the rivet diameter ($3(^3\!/_{16}) = {}^9\!/_{16} < 3$).

The hole diameter meets the requirements of Section J.4.2 because it is no more than 4% greater than the rivet diameter ($0.191/(^3\!/_{16}) = 1.02$)

Section J.4.6 gives the rivet's allowable shear strength as

$$R_n/\Omega = \pi D_h^2 F_{su}/(4\Omega) = \pi(0.191)^2(26)/(4(2.34)) = 0.32 \text{ k}$$

The allowable shear per inch is (0.32 k)/(3 in.) = 0.11 k/in. > 0.09 k/in.

Section J.4.7 gives the rivet's allowable bearing as

$$R_n/\Omega = d_e t F_{tu}/\Omega = (3)(0.063)(37)/1.95 = 3.59 \text{ k}$$

but shall not exceed

$$2D_h t\, F_{tu} = 2(0.191)(0.063)(37) = 0.89 \text{ k}$$

The allowable bearing per inch is (0.89 k)/(3 in.) = 0.30 k/in. > 0.09 k/in.

Since both bearing and shear are satisfactory, the connection will adequately resist the shear load.

Example 8
BEARING ON A PIN
Illustrating Section J.7

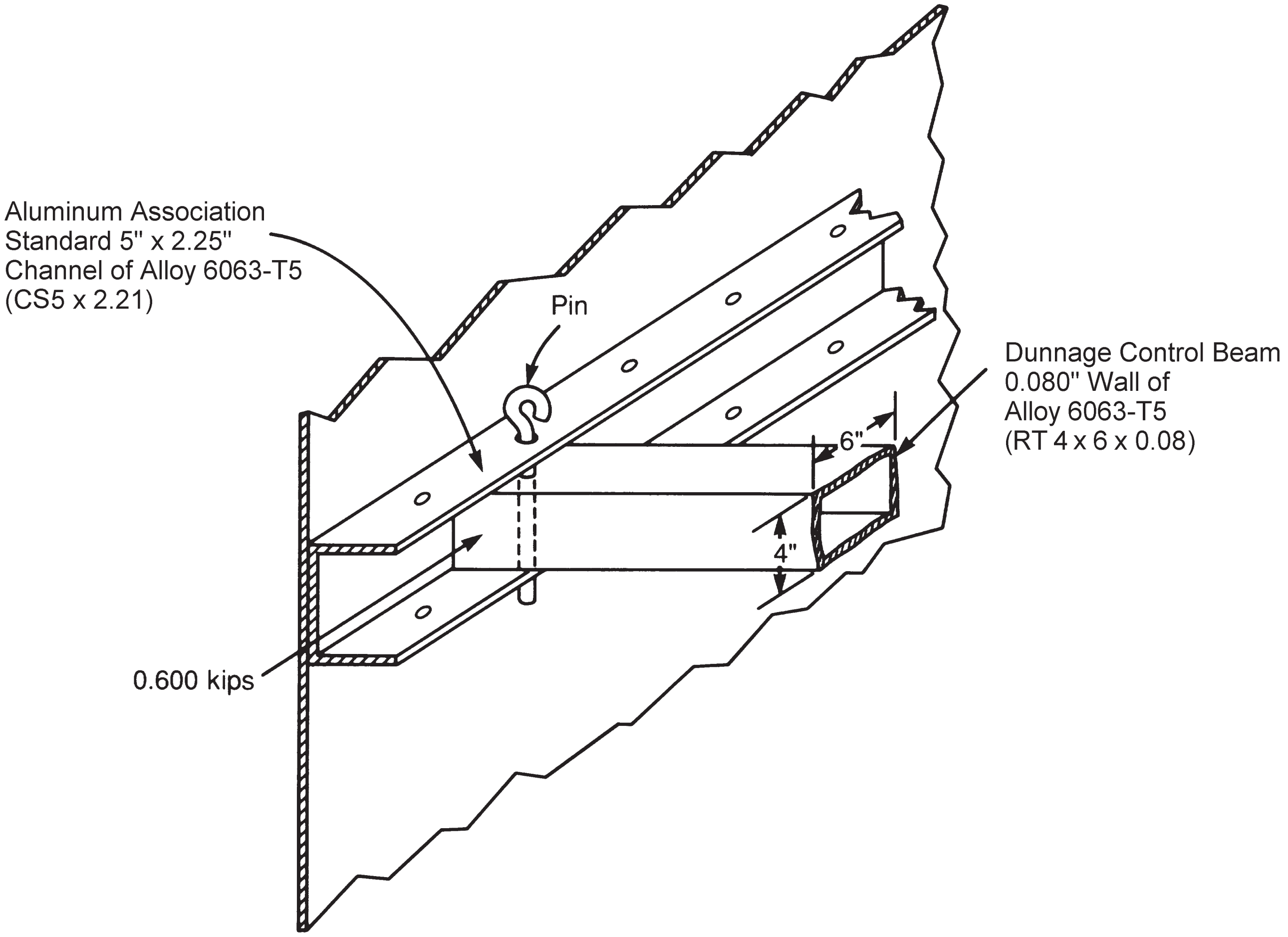


Figure 8

GIVEN:

1. Beam: Hollow rectangular tube 4 in. × 6 in. with wall thickness 0.080 in.
2. End supports: Aluminum Association standard 5 in. × 2.25 in. channel (CS5 × 2.21).
3. Beam load: 1.20 k (1,200 lb) uniformly distributed.
4. Pin: Allowable bending stress 25 ksi.
5. Beam and end support alloy: 6063-T5.
6. Structure type: building

REQUIRED:

The minimum pin size for the end connection.

SOLUTION:

From Part VI Table 2-20
Section J.7: bearing on pins

$F/\Omega = 15$ ksi

From Part VI Beam Formulas Case 6
Simply supported beam, uniformly distributed load,

$R = W/2 = (1.2 \text{ k})/2 = 0.6 \text{ k}$

$A = (0.6 \text{ k})/(15 \text{ k/in}^2) = 0.04 \text{ in}^2$, required bearing area

The bearing area on the pin is the diameter of the pin times the length in bearing.

$D_1 = A/(2t) = (0.04)/(2(0.080)) = 0.25$ in. = diameter required, based on the bearing stress in the beam wall

Determine the pin diameter based on bending of the pin.
From Part V Table 4, the clearance between flanges of the 5 in. channel is:

$C = 5.00 - 2(0.26) = 4.48$ in.

Assuming the beam is at the bottom of the supporting channel, the lever arm for bending is the net clearance plus half the wall thicknesses of the adjacent bearing surfaces.

$L = (4.48 - 4.00) + 0.080/2 + 0.26/2 = 0.65$ in.

A reasonable assumption to determine pin bending is that half of the connection load is transferred at the top of the beam.

$M = LR/2 = (0.65)(0.6/2) = 0.195$ in-k

The section modulus required is

$S = M/(F/\Omega) = (0.195 \text{ in-k})/(25 \text{ k/in}^2) = 0.0078 \text{ in}^3$,

From Part V Table 28, for a round cross section

$S = \pi D^3/32$, which can be solved for D

$D = (32S/\pi)^{1/3} = ((32(0.0078)/\pi)^{1/3} = 0.43$ in.

This diameter is greater than the diameter based on bearing, therefore the required diameter is 0.43 in. Use a $^7/_{16}$ in. diameter pin.

NOTES: For cases in which the bearing load on a pin is toward the edge of the member, the allowable bearing should be reduced as required in Section J.7 of the *Specification.*

Example 9
I BEAM IN AXIAL COMPRESSION
Illustrating Sections E.1, E.3, E.4, and E.5

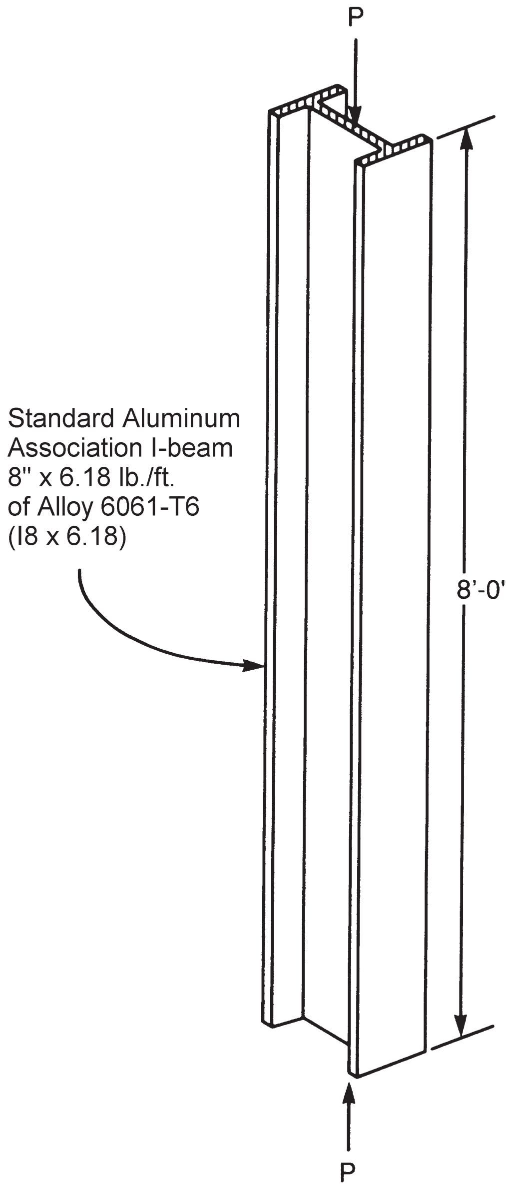


Figure 9

GIVEN:

1. Aluminum Association Standard I-beam I 8 × 6.18
2. Length: 8 ft
3. End conditions: pinned
4. Laterally supported to resist buckling about the weak axis
5. Alloy: 6061-T6
6. Structure type: building

REQUIRED:

The allowable axial compressive strength.

SOLUTION:

From Part V Table 8 the section properties of an 8 in. × 6.18-lb/ft I-beam (I 8 × 6.18) are:

$A = 5.26$ in^2, $r_x = 3.37$ in., $d = 8.00$ in., $b_f = 5.00$ in., $t_f = 0.35$ in., $t_w = 0.23$ in.

Chapter E addresses columns. Section E.1 requires that the allowable compressive strength is the least of the limit states of member buckling, local buckling, and the interaction between member buckling and local buckling, and establishes $\Omega_c = 1.65$ for building structures. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

a) Member buckling is addressed in Section E.3. For flexural buckling, Section E.3.1 gives the slenderness as

$kL/r = (1)(8)(12)/3.37 = 28.5 < S_2 = 66$, so

$F_c/\Omega = 20.3 - 0.127\ (kL/\mathrm{r}) = 20.3 - 0.127(28.5) = 16.7$ ksi

The member buckling stress is $F_c = (16.7)(1.65) = 27.6$ ksi
The allowable axial compressive strength for member buckling is $P_n = (F/\Omega)A_g = (16.7)(5.26) = 87.8$ k

If in place of this doubly symmetric I-beam an unsymmetric open shape such as a channel, lipped angle, or hat shape were used, flexural-torsional buckling should be checked using Section E.3.2.

b) Local buckling is addressed in Section E.4.

Local buckling of the flange (a flat element with one edge supported) is addressed in Section B.5.4.1. The slenderness is

$b/t = (5.00 - 0.23)/(2 \times 0.35) = 6.8$

The slenderness is between $S_1 = 6.7$ and $S_2 = 10.5$, so

$F_c/\Omega = 27.3 - 0.91(6.8) = 21.1$ ksi

The area of the flanges $= A_f = 2(5.00)(0.35) = 3.5$ in^2

Local buckling of the web (a flat element with both edges supported) is addressed in Section B.5.4.2. The slenderness is

$b/t = (8.00 - 2(0.35))/0.23 = 31.7$

The slenderness is between $S_1 = 20.8$ and $S_2 = 33$, so

$F_c/\Omega = 27.3 - 0.291(31.7) = 18.1$ ksi

The area of the web $= A_w = (8.00 - 2(0.35))(0.23)$
$= 1.679$ in^2

The weighted average allowable local buckling strength is

$P_n/\Omega = (21.1)(3.5) + (18.1)(1.679) + (35/1.65)$
$(5.26 - 3.5 - 1.679) = 106.0$ k

c) The interaction between member buckling and local buckling is addressed in Section E.5. Elastic buckling stresses are given in Section B.5.6.

The elastic buckling stress of the flange (a flat element with one edge supported) for the slenderness of 6.8 determined in b) above is

$$F_e = \frac{\pi^2 E}{(5.0b/t)^2} = \frac{\pi^2(10{,}100)}{(5.0(6.8))^2} = 86.2 \text{ ksi}$$

The elastic buckling stress of the web (a flat element with both edges supported) for the slenderness of 31.7 determined in b) above is

$$F_e = \frac{\pi^2 E}{(1.6b/t)^2} = \frac{\pi^2(10{,}100)}{(1.6(31.7))^2} = 38.7 \text{ ksi} > 27.6 \text{ ksi}$$

= member buckling stress; therefore, the strength is not reduced by interaction between member and local buckling.

The allowable axial compressive strength is the lesser of 87.8 k and 106.0 k, which is 87.8 k.

Example 10
CORNER ANGLE OF A LATTICED BOX COLUMN
Illustrating Sections E.1, E.3, E.4, and E.5

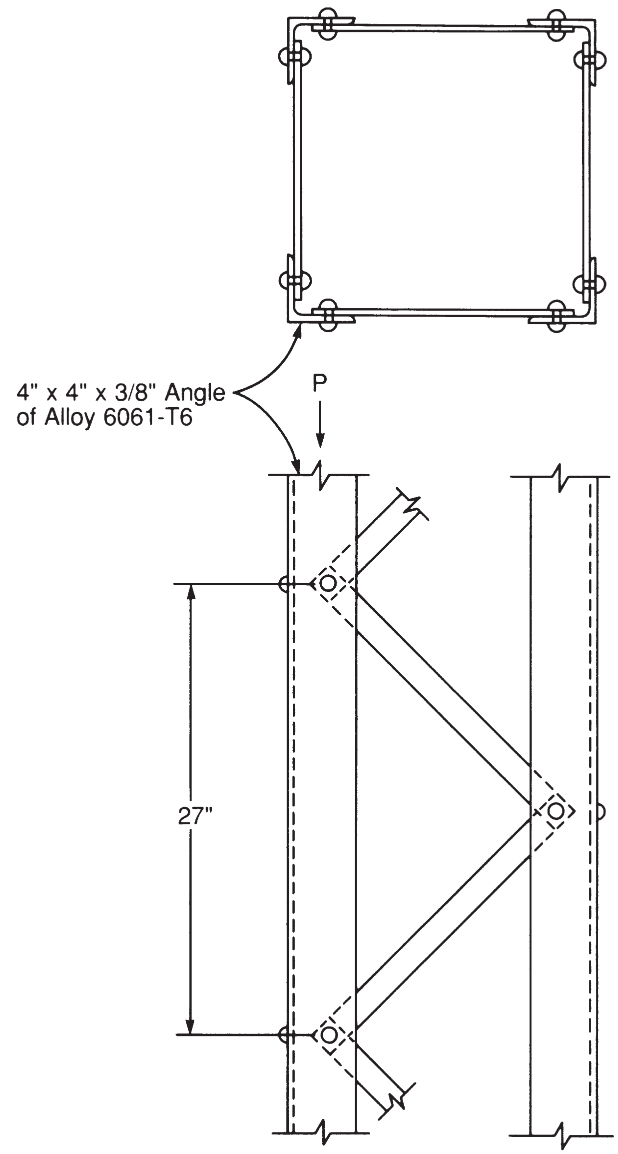


Figure 10

GIVEN:

1. Latticed box section column
2. Corner components: 4 in. × 4 in. × $3/8$ in. angle
3. Alloy: 6061-T6
4. Spacing of lattice points: 27 in. o.c.
5. Connection of lattice: Riveted
6. Structure type: building

REQUIRED:

Allowable axial compressive strength of a corner angle between lattice points.

SOLUTION:

From Part V, Table 14, the section properties of the 4 in. × 4 in. × $3/8$ in. angle are

$A = 2.86$ in.^{2}, $r_x = r_y = 1.22$ in., $r_z = 0.766$ in., $I_x = I_y = 4.26$ in^4

The warping constant $C_w = 0$ for an angle. The torsional constant is

$J = (1/3)(0.375)^3(4 + 3.625) = 0.134$ in^4

x_o, y_o = coordinates of the shear center with respect to the centroid

$x_o = y_o = 1.12 - 0.5(3/8) = 0.9325$ in.

Chapter E addresses columns. Section E.1 requires that the allowable compressive strength is the least of the limit states of member buckling, local buckling, and the interaction between member buckling and local buckling, and establishes $\Omega_c = 1.65$ for building structures. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

a) Member buckling is addressed in Section E.3. Section E.3.2 addresses flexural-torsional buckling for unsymmetric shapes such as an angle. The elastic buckling stress F_e is the lowest root of the equation

$$(F_e - F_{ex})(F_e - F_{ey})(F_e - F_{ez}) - F_e^2(F_e - F_{ey})(x_o/r_o)^2 - F_e^2(F_e - F_{ex})(y_o/r_o)^2 = 0$$

where

$$r_o^2 = x_o^2 + y_o^2 + \frac{I_x + I_y}{A_g} = 2(0.9325)^2 + 2(4.26)/2.86$$

$$= 4.72 \text{ in}^2$$

$$F_{ex} = F_{ey} = \frac{\pi^2 E}{\left(\frac{k_x L_x}{r_x}\right)^2} = \pi^2(10{,}100)/(27/1.22)^2 = 203.5 \text{ ksi}$$

$$F_{ez} = \frac{1}{A_g r_o^2}\left(GJ + \frac{\pi^2 E C_w}{(k_z L_z)^2}\right) = \frac{(3/8)(10{,}100)(0.134)}{(2.86)(4.72)}$$

$$= 37.6 \text{ ksi}$$

Solving for F_e by trial and error, $F_e = 34.9$ ksi.

$$(kL/r_e) = \pi\sqrt{\frac{E}{F_e}} = \pi\sqrt{\frac{10{,}100}{34.9}} = 53.4 < S_2 = 66, \text{ so}$$

$$F_c/\Omega = 20.3 - 0.127(kL/r) = 20.3 - 0.127(53.4) = 13.5 \text{ ksi}$$

The member buckling stress is $F_c = (13.5)(1.65)$ $= 22.3$ ksi

The allowable axial compressive strength for member buckling is $P_n = (F/\Omega)A_g = (13.5)(2.86) = 38.6$ k

b) Local buckling is addressed in Section E.4. Local buckling of the angle leg (a flat element with one edge supported) is addressed in Section B.5.4.1. The slenderness is

$b/t = (4.00 - 0.375)/0.375 = 9.7$

The slenderness is between $S_1 = 6.7$ and $S_2 = 10.5$, so

$F_c/\Omega = 27.3 - 0.91(9.7) = 18.5$ ksi

The allowable axial compressive strength for local buckling is $P_n = (F/\Omega)A_g = (18.5)(2.86) = 52.9$ k

c) The interaction between member buckling and local buckling is addressed in Section E.5. Elastic buckling stresses are given in Section B.5.6.

The elastic buckling stress of the leg (a flat element with one edge supported) for the slenderness of 9.7 determined in b) above is

$$F_e = \frac{\pi^2 E}{(5.0b/t)^2} = \frac{\pi^2(10{,}100)}{(5.0(9.7))^2} = 42.4 \text{ ksi} > 22.3 \text{ ksi}$$

= member buckling stress; therefore, the strength is not reduced by interaction between member and local buckling.

The allowable axial compressive strength is the lesser of 38.6 k and 52.9 k, which is 38.6 k.

NOTES: The allowable axial compressive strength of the latticed column must also be determined for full length buckling resistance in accordance with Section E.3. The allowable strength is the lesser of this strength and four times the allowable strength of the corner angle computed above, whichever is smaller.

The lattice diagonals brace the corner angles and must have adequate stiffness and strength to meet the requirements of Appendix 6.

Example 11
WIDE FLANGE COLUMN
Illustrating Sections E.1, E.3, E.4, and E.5

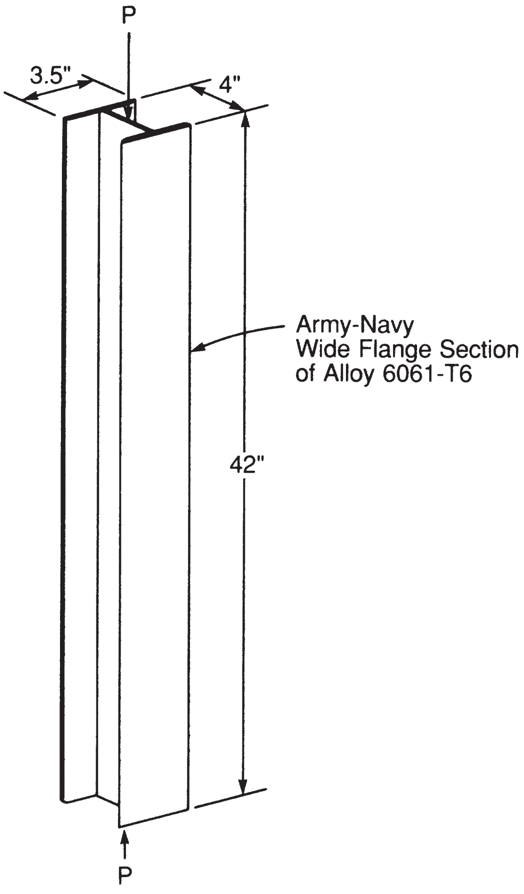


Figure 11

GIVEN:

1. Column section: 4 in. × 3.50 in. × 3.06 lb/ft Army-Navy wide flange section. (WF (A-N) 4 × 3.06)
2. Length: 42 in.
3. End conditions: Pinned.
4. Alloy: 6061-T6.
5. Structure type: building

REQUIRED:

Allowable axial compressive strength.

SOLUTION:

From Part V, Table 10, the section properties of WF (A-N) 4 × 3.06 are

$A = 2.60$ in^2, $b = 3.50$ in., $t = 0.250$ in., $r_x = 1.64$ in.,
$r_y = 0.793$ in.

Chapter E addresses columns. Section E.1 requires that the allowable compressive strength is the least of the limit states of member buckling, local buckling, and the interaction between member buckling and local buckling, and establishes $\Omega_c = 1.65$ for building structures. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

a) Member buckling is addressed in Section E.3. For flexural buckling, Section E.3.1 gives the slenderness as

$kL/r = (1)(42)/0.793 = 53.0 < S2 = 66$, so

$$F_c/\Omega = 20.3 - 0.127(kL/r) = 20.3 - 0.127(53.0) = 13.6 \text{ ksi}$$

The member buckling stress is $F_c = (13.6)(1.65) = 22.4$ ksi

The allowable axial compressive strength for member buckling is $P_n = (F/\Omega)\,A_g = (13.6)(2.60) = 35.4$ k

b) Local buckling is addressed in Section E.4.

Local buckling of the flange (a flat element with one edge supported) is addressed in Section B.5.4.1. The slenderness is

$b/t = (3.50 - 0.25)/(2 \times 0.25) = 6.5 < 6.7 = S_1$,
so $F_c/\Omega = 21.2$ ksi

Local buckling of the web (a flat element with both edges supported) is addressed in Section B.5.4.2. The slenderness is

$b/t = (4.00 - 2(0.25))/0.25 = 14 < 20.8 = S_1$, so

$F_c/\Omega = 21.2$ ksi

The weighted average allowable local buckling strength is

$P_n/\Omega = (21.2)(2.60) = 55.1$ k

c) The interaction between member buckling and local buckling is addressed in Section E.5. Elastic buckling stresses are given in Section B.5.6.

The elastic buckling stress of the web (a flat element with both edges supported) for the slenderness of 14 determined in b) above is

$$F_e = \frac{\pi^2 E}{(1.6b/t)^2} = \frac{\pi^2(10{,}100)}{(1.6(14))^2} = 199 \text{ ksi}$$

The elastic buckling stress of the flange (a flat element with one edge supported) for the slenderness of 6.5 determined in b) above is

$$F_e = \frac{\pi^2 E}{(5.0b/t)^2} = \frac{\pi^2(10{,}100)}{(5.0(6.5))^2} = 94.4 \text{ ksi} > 22.4 \text{ ksi}$$

= member buckling stress; therefore, the strength is not reduced by interaction between member and local buckling.

The allowable axial compressive strength is the lesser of 35.4 k and 55.1 k, which is 35.4 k.

Example 12
SQUARE TUBE COLUMN
Illustrating Sections E.1, E.3, E.4, and E.5

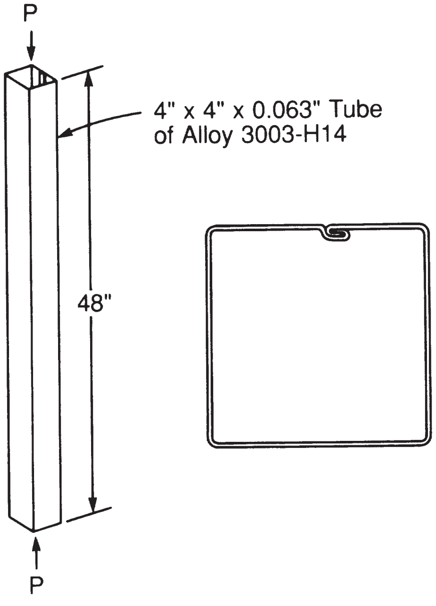


Figure 12

GIVEN:

1. 4 in. square tube column formed with lock-seam from 0.063 in. sheet.
2. Length: 48 in.
3. End conditions: Pinned.
4. Alloy: 3003-H14.
5. Structure type: building

REQUIRED:

Allowable axial compressive strength.

SOLUTION:

From Part V, Table 28, hollow square section properties are

$$A = 4^2 - (4.00 - 0.063 \times 2)^2$$

$$= 0.992 \text{ in}^2$$

$$r = \sqrt{\frac{d_1^2 + d_2^2}{12}} = \sqrt{\frac{4^2 + (4 - 0.63(2))^2}{12}} = 1.61 \text{ in.}$$

NOTE: This method assumes sharp corners, whereas the actual corners of roll formed sections are rounded. Where the corner radius is small in comparison with the width of the section, this method is sufficiently accurate for practical purposes.

Chapter E addresses columns. Section E.1 requires that the allowable compressive strength is the least of the limit states of member buckling, local buckling, and the interaction between member buckling and local buckling, and establishes $\Omega_c = 1.65$ for building structures. Allowable stresses for 3003-H14 given in Part VI Table 2-2 are used below.

a) Member buckling is addressed in Section E.3. For flexural buckling, Section E.3.1 gives the slenderness as

$kL/r = (1)(48)/1.61 = 29.8 < S_2 = 138$, so

$F_c/\Omega = 8.1 - 0.039\ (kL/r) = 8.1 - 0.039(29.8) = 6.9$ ksi

The member buckling stress is $F_c = (6.9)(1.65) = 11.4$ ksi

The allowable axial compressive strength for member buckling is $P_n = (F/\Omega)\ A_g = (6.9)(0.992) = 6.8$ k

b) Local buckling is addressed in Section E.4.

Local buckling of a side (a flat element with both edges supported) is addressed in Section B.5.4.2. The slenderness is

$b/t = (4.00 - 2(0.063))/0.063 = 61.5 > 60 = \mathrm{S}_2$,

so $F_c/\Omega = 333/(61.5) = 5.4$ ksi

The weighted average allowable local buckling strength is

$F_c A_g/\Omega = (5.4)(0.992) = 5.4$ k

c) The interaction between member buckling and local buckling is addressed in Section E.5. Elastic buckling stresses are given in Section B.5.6.

The elastic buckling stress of a side (a flat element with both edges supported) for the slenderness of 61.5 determined in b) above is

$$F_e = \frac{\pi^2 E}{(1.6b/t)^2} = \frac{\pi^2(10{,}100)}{(1.6(61.5))^2} = 10.3 \text{ ksi} < 11.4 \text{ ksi}$$

= member buckling stress; therefore, the allowable strength cannot exceed:

$$P_n/\Omega = \left(\frac{\pi^2 E}{(kL/r)^2}\right)^{1/3} \frac{F_e^{2/3} A_g}{\Omega} = \left(\frac{\pi^2(10{,}100)}{(29.8)^2}\right)^{1/3} \frac{10.3^{2/3}(0.992)}{1.65}$$

$$= 13.8 \text{ k}$$

The allowable axial compressive strength is the least of 6.8 k, 5.4 k, and 13.8 k, which is 5.4 k.

NOTES: The area of the lockseam is generally small and can be neglected. However, the seam must resist longitudinal slippage, otherwise the shape would be classed as an "open section" and would be subject to combined torsional and lateral buckling; see notes for Example 10. From Part VI, Table 3-1, 0.063 in. thick 3003-H14 is satisfactory for a zero bend radius.

If the corner radii are large, they should be checked using Section B.5.4.5.

Example 13
COLUMN WITH INTERMEDIATE STIFFENERS
Illustrating Section B.5.4.4

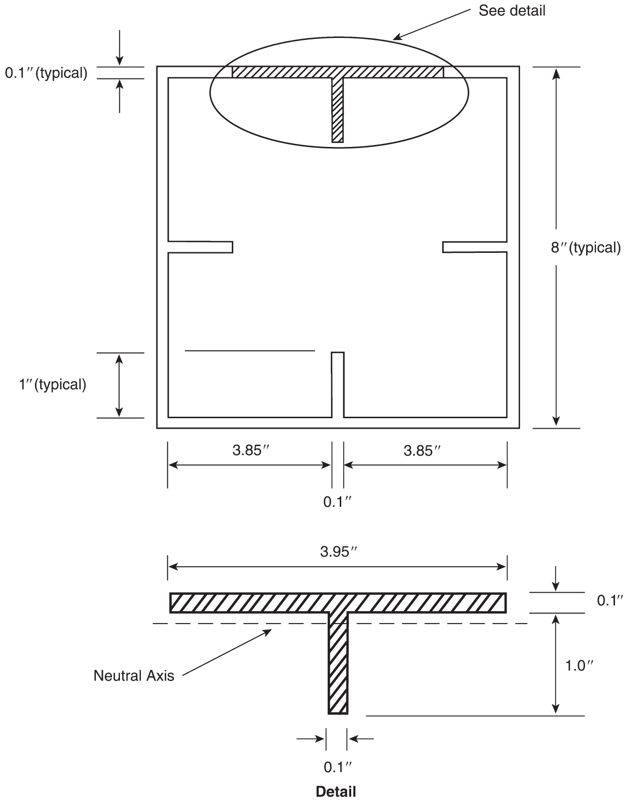


Figure 13

GIVEN:

1. An 8 in. square tube column, with 0.10 in. thick walls and 0.10 in. thick by 1 in. long stiffeners at the middle of each side.
2. Alloy: 6061-T6 extrusion.
3. Structure type: building

REQUIRED:

Allowable local buckling compressive stress.

SOLUTION:

Section B.5.4.4 addresses uniform compression of flat elements supported on both edges and with an intermediate stiffener.

The moment of inertia I_o used in Section B.5.4.4 is of the area shown in the detail of Figure 13.

The area width is $3.85 + 0.1 = 3.95$ in.
The element width $b = 3.85$ in.
The element thickness $t = 0.1$ in.

Properties A_s and I_o are calculated from Part V, Table 28:

$I_n = b_n d_n^3/12$, where b_n is the width and d_n is the height
A_n = area of an element
Y_n = vertical distance from bottom fiber to the centroid of the element

n	b_n	d_n	A_n	Y_n	AY_n	AY_n^2	I_n
1	3.95	0.1	0.395	1.05	0.4147	0.4355	0.0003
2	0.1	1.0	0.1	0.5	0.05	0.025	0.0083
	Totals		0.495		0.4647	0.4605	0.0086

$$c = \frac{\Sigma A_n Y_n}{\Sigma A_n} = \frac{0.4647}{0.495} = 0.9389 \text{ in.}$$

$$I_o = \Sigma(A_n Y_n^2) - c^2 \Sigma A_n + \Sigma I_n$$

$$I_o = 0.4605 - (0.9389)^2\,(0.495) + (0.0086) = 0.03275$$

$$\lambda_s = (4.62)\frac{3.85}{0.1}\sqrt{\frac{1 + \frac{(1.0)(0.1)}{(3.85)(0.1)}}{1 + \sqrt{1 + \frac{10.67(0.03275)}{3.85(0.1)^3}}}}$$

$$\lambda_s = 61.4 < 66 = S_2$$

$$F_1/\Omega = 23.9 - 0.149\,(61.4) = 14.8 \text{ ksi}$$

Check the flat elements on either side of the stiffener:

$$b/t = \frac{3.85}{0.1} = 38.5 > 33 = S_2$$

from Section B.5.4.2

$$F_2/\Omega = 580/38.5 = 15.1 \text{ ksi} > 14.8 \text{ ksi} = F_1$$

So $F_c/\Omega = F_1/\Omega = 14.8$ ksi

Example 14
ROUND TUBE COLUMN
Illustrating Sections E.1, E.3, and E.4

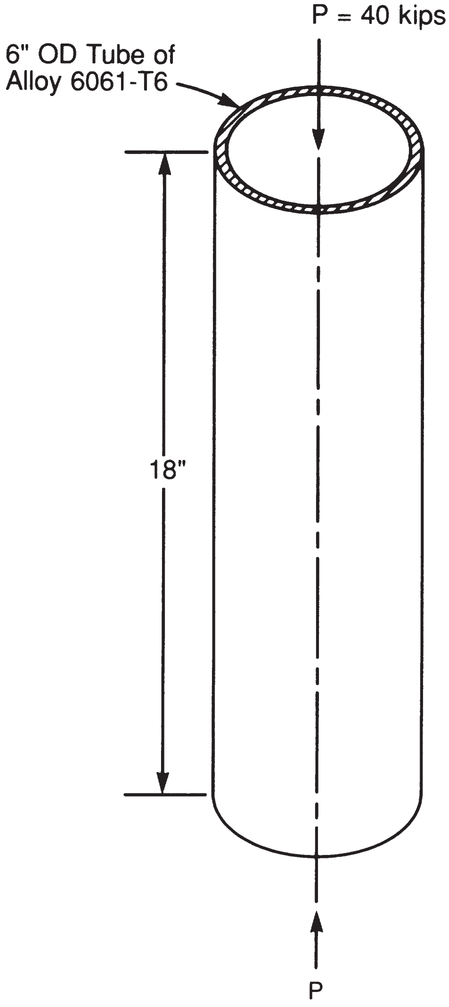


Figure 14

GIVEN:

1. Shape: Round tube, 6 in. OD (outside diameter).
2. Load: 40 k (40,000 lb), concentric.
3. Length: 18 in.
4. Alloy: 6061-T6.
5. End Conditions: pinned.
6. Structure type: building

REQUIRED:

The wall thickness of a standard tube that has an allowable axial compressive strength of at least 40 k.

SOLUTION:

From Part V, Table 21, round tubes, the radius of gyration r of 6 in. OD tubes ranges from 1.80 in. to 2.08 in.. Select from the table the trial wall thickness of 0.188 in. for which $A = 3.43$ in^2 and $r = 2.06$ in..

Chapter E addresses columns. Section E.1 establishes $\Omega_c = 1.65$ for building structures. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

a) Member buckling is addressed in Section E.3. For flexural buckling, Section E.3.1 gives the slenderness as

$kL/r = (1)(18)/2.06 = 8.7 < S_2 = 66$, so

$F_c/\Omega = 20.3 - 0.127\ (kL/r) = 20.3 - 0.127(8.7) = 19.2$ ksi

The allowable axial compressive strength for member buckling is $(F/\Omega)\ A_g = (19.2)(3.43) = 65.8$ k > 40 k

b) Local buckling is addressed in Section E.4.

Local buckling of a curved element supported on both edges is addressed in Section B.5.4.5. The slenderness is

$R_b/t = (6.0 - 0.188)/2/0.188 = 15.5 < 27.6 = S_1$, so

$F_c/\Omega = 21.2$ ksi

The weighted average allowable local buckling strength is

$A_gF_c/\Omega = (21.2)(3.43) = 72.7$ k > 40 k

The wall thickness $t = 0.188$ in. is satisfactory.

Example 15
I-BEAM IN BENDING
Illustrating Sections F.2, F.8, and G.2

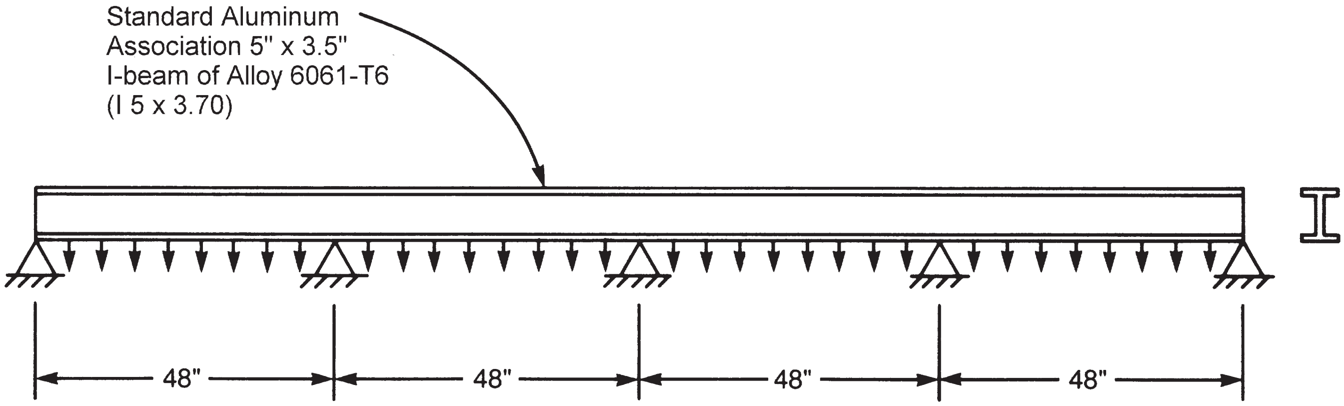


Figure 15

GIVEN:

1. Section: Aluminum Association Standard I-beam I5 × 3.70
2. Beam length: 16 ft. with lateral supports at vertical supports only.
3. Vertical support spacing 4 ft. o.c. (first support at end of beam).
4. Alloy: 6061-T6.
5. Structure type: building

REQUIRED:

Allowable uniform load that can be applied to the bottom flange.

SOLUTION:

Part V, Table 8, gives the section properties:

$S_x = 5.58$ in^3, $b = 3.5$ in., $t_w = 0.19$ in., $t_f = 0.32$ in.,
$r_y = 0.853$ in., $I_y = 2.29$ in^4, $J = 0.0984$ in^4

The flange's slenderness ratio is
$b/t = (3.5 - 0.19)/2/0.32 = 5.2$

The web's slenderness ratio is
$b/t = (5.0 - 2(0.32))/0.19 = 22.9$

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure of building-type structures. Section F.2 requires that Sections F.2.1, F.2.3, and F.8 be used to determine the flexural strength of open shapes. Section G.2 addresses the shear strength of flat webs. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

a) Section F.2.1 addresses lateral-torsional buckling. To determine the slenderness ratio $\frac{L_b}{r_y\sqrt{C_b}}$, Section F.1.1 allows the bending coefficient C_b to be conservatively taken as 1.

$$\frac{L_b}{r_y} = \frac{48}{0.853} = 56.3 < S_2 = 79, \text{ so}$$

$$F_b/\Omega = 23.9 - 0.124\,\frac{L_b}{r_y}$$

$$F_b/\Omega = 23.9 - 0.124\,(56.3) = 16.9 \text{ ksi}$$

The lateral-torsional buckling stress
$F_b = (1.65)(16.9 \text{ ksi}) = 27.9$ ksi

b) Section F.2.3 addresses interaction between local buckling and lateral-torsional buckling.

The flange's elastic buckling stress given in Section B.5.6 is

$$F_e = \frac{\pi^2 E}{(5.0b/t)^2} = \frac{\pi^2(10{,}000)}{(5.0(5.2))^2} = 147 \text{ ksi} > 27.9 \text{ ksi}$$

Because the flange's elastic buckling stress is not less than the beam's lateral-torsional buckling stress, the beam's flexural capacity is not limited by the interaction between local buckling and lateral-torsional buckling.

c) Section F.8 addresses elements of flexural members.
   1) Section F.8.1 addresses tension.
      Section F.8.1.1 addresses elements in uniform tension (the flange), for which $F_b/\Omega = 19.5$ ksi,
      Section F.8.1.2 addresses elements in flexure (the web), for which $F_b/\Omega = 27.6$ ksi.

2) Section F.8.2 addresses compression.

Section B.5.4.1 addresses the flange;

$b/t = 5.2 < 6.7 = S_1$, so $F_b/\Omega = 21.2$ ksi

Section B.5.5.1 addresses the web;

$b/t = 22.9 < 49.3 = S_1$, so $F_b/\Omega = 27.6$ ksi

The least of these allowable stresses is for lateral-torsional buckling; therefore, $F_b/\Omega = 16.9$ ksi and the allowable moment is $M = FS_x = 16.9(5.58) = 94.3$ in-k.

From Part VI Beam Formulas Case 43, continuous beam of four equal spans with a uniformly distributed load, the maximum bending moment is

$$M = \frac{-168wL^2}{1568}$$

Rewriting to solve for w,

$$w = \frac{1568M}{168L^2} = \frac{1568(94.3)}{168(48)^2} = 0.382 \text{ k/in.}$$

= allowable distributed load for flexure

The section is symmetrical about its X axis; therefore, the allowable positive moment is equal to the allowable negative moment. Thus, the minus sign for w may be removed.

d) Section G.2 addresses web shear

$b/t = 22.9 < S_1 = 35.3$, so $F_s/\Omega = 12.7$ ksi

$A = dt_w = (5.00)(0.19) = 0.95 \text{ in}^2$ = area of web

$V = AF_s/\Omega = 0.95(12.7) = 12.1$ k, allowable shear

From Part VI Beam Formulas Case 43, the maximum shear is

$V = \dfrac{17wL}{28}$, which can be written

$w = \dfrac{28V}{17L}$, which w is unknown

$w = \dfrac{28(12.1)}{17(48)} = 0.415$ k/in. = allowable distributed load for shear

Using the smaller of the loads for flexure and shear, the allowable uniform load is 0.382 k/in.

NOTES: Example 3 notes also apply to this example.

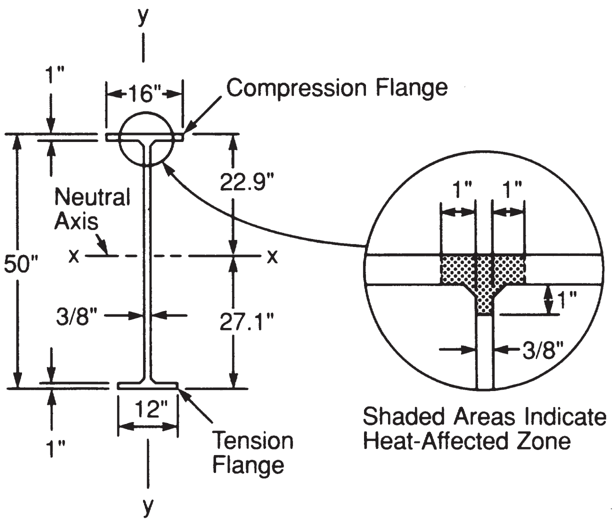
A more accurate flexural strength can be determined by using Section F.2.2 to compute r_{ye}. For shapes symmetric about the bending axis and where the load acts downward on the bottom flange (away from the beam's shear center), Section F.2.2.1 gives:

$$r_{ye} = \frac{1}{1.7}\sqrt{\frac{2.29(5.00)}{5.58}\sqrt{\left[0.5 + \sqrt{1.25 + 0.152\frac{0.0984}{2.29}\left(\frac{48}{5.00}\right)^2}\right]}}$$

$= 0.984$ in.

r_{ye} may be used in place of $r_y = 0.853$ in. to compute the lateral-torsional buckling strength.

Example 16
WELDED GIRDER IN BENDING
Illustrating Sections F.2, F.8, F.9



Welded Beam of Alloy 5456-H321

Figure 16

GIVEN:

1. Welded girder, see Figure 16
2. Lateral support spacing: compression flange, 10 ft o.c.
3. Alloy: 5456-H321
4. Structure type: bridge
5. Number of load cycles: 500,000

REQUIRED:

Allowable bending moment with the top flange in compression.

SOLUTION:

To compute section properties, see Part V, Table 28.

The moment of inertia of a rectangle about its centroid is

$$In = b_n d_n^3/12$$

where b_n is the width, and d_n, is the height.

A_n = area of an element

Y_n = vertical distance from bottom fiber to centroid of element

n	b_n	d_n	A_n	Y_n	AY_n	AY_n^2	I_n
1	16.0	1.00	16.0	49.5	792	39204	1
2	0.375	48.0	18.0	25.0	450	11250	3456
3	12.0	1.00	12.0	0.5	6	3	1
	Totals		46.0		1248	50457	3458

The height of the centroid of the section

$$c_t = \frac{\Sigma A_n Y_n}{\Sigma A_n} = \frac{1248}{46.0} = 27.1 \text{ in.}$$

$$I_x = \sum(A_n Y_n^2) - c_t^2 \sum A_n + \sum I_n = 20{,}132 \text{ in}^4$$

For the compression flange,

$$c_c = 50.0 - 27.1 = 22.9 \text{ in.}$$

The section modulus for compression is

$$S_c = I_x/c_c = 20{,}132/22.9 = 879 \text{ in}^3$$

The section modulus for tension is

$$S_t = I_x/c_t = 20{,}132/27.1 = 743 \text{ in}^3$$

Section F.2.2.2 addresses flexure of singly symmetric shapes unsymmetric about the bending axis and allows computing r_y by treating both tension and compression flanges identical to the compression flange of the actual section. To compute the area and the moment of inertia about the *Y* axis of such a section:

n	b_n	d_n	A_n	I_n
1	1.0	16.0	16.0	341
2	48.0	0.375	18.0	0
3	1.0	16.0	16.0	341
	Totals		50.0	682

$$I_y = \sum I_n = 682 \text{ in}^4 \qquad A_y = 50.0 \text{ in}^2$$

$$r_y = \sqrt{\frac{I_y}{A_y}} = \sqrt{\frac{682}{50}} = 3.69 \text{ in.}$$

For the portion of the cross section outside the weld-affected zone, Table A.3.4 gives mechanical properties for 5456-H321 plate. The web is ⅜ in. thick plate (with F_{tu} = 46 ksi) and the flange is 1 in. thick plate (with F_{tu} = 44 ksi). For design, conservatively use the mechanical properties of the flange throughout the section:

$$E = 10{,}400 \text{ ksi}, F_{tu} = 44 \text{ ksi}, F_{ty} = 31 \text{ ksi}, F_{cy} = 25 \text{ ksi}$$

From Part VI, Table 1-1, the buckling constants for the unwelded material are

$B_c = 29.0$ $\quad B_p = 34.6$ $\quad B_{br} = 46.1$

$D_c = 0.187$ $\quad D_p = 0.245$ $\quad D_{br} = 0.376$

$C_c = 103$ $\quad C_p = 94$ $\quad C_{br} = 82$

From Table B.4.3, $k_1 = 0.50$, $k_2 = 2.04$

For the portion of the cross section in the weld-affected zone, Table A.3.5 gives mechanical properties for 5456-H321 plate:

$E = 10{,}400$ ksi, $F_{tu} = 42$ ksi, $F_{ty} = 19$ ksi, $F_{cy} = 19$ ksi

From Part VI, Table 1-2, the buckling constants for the weld affected material are

$B_c = 21.6$ $\quad B_p = 25.7$ $\quad B_{br} = 34.1$

$D_c = 0.121$ $\quad D_p = 0.156$ $\quad D_{br} = 0.240$

$C_c = 119$ $\quad C_p = 110$ $\quad C_{br} = 95$

From Table B.4.3, $k_1 = 0.50$, $k_2 = 2.04$

Section F.1 establishes safety factors of 2.20 on tensile rupture and 1.85 on all other limit states for flexure of bridge-type structures. Section F.2 requires that Sections F.2.1, F.2.3, and F.8 be used to determine the flexural strength of open shapes subject to lateral-torsional buckling.

a) Section F.2.1 addresses lateral-torsional buckling. To determine the slenderness ratio $\dfrac{L_b}{r_y\sqrt{C_b}}$, Section F.1.1 allows the bending coefficient C_b to be conservatively taken as 1.

For a beam with no portion weld-affected:

$$\frac{L_b}{r_y} = \frac{120}{3.69} = 32.5 < S_2 = 1.2C_c = 1.2(103) = 124, \text{ so}$$

$$F_{bo}/\Omega = \left(B_c - D_c\frac{L_b}{1.2r_y}\right)/\Omega$$
$$= (29.0 - 0.187(32.5/1.2))/1.85 = 12.9 \text{ ksi}$$

$M_{no}/\Omega = (F_{bo}/\Omega)S_c = (12.9 \text{ k/in}^2)(879 \text{ in}^3) = 11{,}370$ in-k

For a beam entirely weld-affected:

$$\frac{L_b}{r_y} = \frac{120}{3.69} = 32.5 < S_2 = 1.2C_c = 1.2(119) = 143, \text{ so}$$

$$F_{bw}/\Omega = \left(B_c - D_c\frac{L_b}{1.2r_y}\right)/\Omega$$
$$= (21.6 - 0.121(32.5/1.2))/1.85 = 9.9 \text{ ksi}$$

$M_{nw}/\Omega = (F_{bw}/\Omega)S_c = (9.9 \text{ k/in}^2)(879 \text{ in}^3) = 8{,}710$ in-k

Section F.9.2 provides the lateral-torsional buckling strength of longitudinally welded beams as

$$M_n = M_{no}\,(1 - A_{wz}/A_f) + M_{nw}\,(A_{wz}/A_f)$$

where

$A_{wz} = (1 + 0.375 + 1)(1) + (1)(0.375) = 2.75 \text{ in}^2$
$A_f = (16)(1) + (22.9/3 - 1)(0.375) = 18.5 \text{ in}^2$

$$M_n/\Omega = 11{,}370(1 - 2.75/18.5) + 8{,}710(2.75/18.5)$$
$$= 10{,}970 \text{ in-k}$$

The lateral-torsional buckling stress $F_b = \Omega\, M_n/S_c$
$F_b = (1.85)(10{,}970 \text{ in-k}/879 \text{ in}^3) = 23.1 \text{ k/in}^2$

b) Section F.2.3 addresses interaction between local buckling and lateral-torsional buckling.

The flange's slenderness ratio is

$b/t = (16 - 0.375)/2/1 = 7.8$

The flange's elastic buckling stress given in Section B.5.6 is

$$F_e = \frac{\pi^2 E}{(5.0b/t)^2} = \frac{\pi^2(10{,}400)}{(5.0(7.8))^2} = 67.5 \text{ ksi} > 23.1 \text{ ksi}$$

Because the flange's elastic buckling stress is not less than the beam's lateral-torsional buckling stress, the beam's flexural capacity is not limited by the interaction between local buckling and lateral-torsional buckling.

c) Section F.8 addresses elements of flexural members.
   1) Section F.8.1 addresses tension.
      Section F.8.1.1 addresses elements in uniform tension (the flange).
      The weld affected area of the tension flange is $A_{wz} = 2.375(1) = 2.375 \text{ in}^2$
      The gross area of the tension flange is $A_{wz} = 12(1) = 12 \text{ in}^2$

For longitudinally welded elements the allowable stress is the lesser of

$$F_b/\Omega = [F_{ty}(1 - A_{wz}/A_g) + F_{tyw}A_{wz}/A_g]/1.85$$
$$= [31(1 - 2.375/12) + 19(2.375/12)]/1.85$$
$$= 15.5 \text{ ksi, and}$$

$$F_b/\Omega = [F_{tu}(1 - A_{wz}/A_g)/k_t + F_{tuw}A_{wz}/A_g]/2.20$$
$$= [44(1 - 2.375/12) + 42(2.375/12)]/2.20$$
$$= 19.8 \text{ ksi}$$

So the allowable tensile stress in the flange is $F_{tf}/\Omega = 15.5$ ksi

Section F.8.1.2 addresses elements in flexure (the web).
The weld affected area of the web in tension is $A_{wz} = 0.375(1) = 0.375 \text{ in}^2$
The gross area of the web in tension is $A_{wz} = (27.1 - 1)(0.375) = 9.79 \text{ in}^2$

For longitudinally welded elements the allowable stress is the lesser of

$$F_b/\Omega = 1.3[F_{ty}(1 - A_{wz}/A_g) + F_{tyw}A_{wz}/A_g]/1.85$$
$$= 1.3[31(1 - 0.375/9.79) + 19(0.375/9.79)]/1.85$$
$$= 21.5 \text{ ksi, and}$$

$F_b/\Omega = 1.42[F_{tu}(1 - A_{wz}/A_g)/k_t + F_{tuw}A_{wz}/A_g]/2.20$

$= 1.42[44(1 - 0.375/9.79) + 42(0.375/9.79)]/2.20$

$= 28.4$ ksi

So the allowable tensile stress in the web is $F_{tw}/\Omega = 21.5$ ksi

2) Section F.8.2 addresses compression. Section B.5.4.1 addresses the flange. The slenderness ratio of the compression flange is

$b/t = (16 - 3/8)2/1 = 7.8$

For the unwelded portion of the flange

$S_1 = (B_p - F_{cy})/(5.0D_p) = (34.6 - 25)/(5.0(0.245)) = 7.8$

$b/t = 7.8 \leq 7.8 = S_1$, so $F_{co}/\Omega = F_{cy}/\Omega = (25 \text{ ksi})/1.85 = 13.5$ ksi

For the welded portion of the flange

$S_1 = (B_p - F_{cy})/(5.0D_p) = (25.7 - 19)/(5.0(0.156)) = 8.6$

$b/t = 7.8 \leq 8.6 = S_1$, so $F_{cw}/\Omega = F_{cyw}/\Omega = (19 \text{ ksi})/1.85 = 10.3$ ksi

Section B.5.4 provides the strength of the compression flange as

$F_{cf} = F_{co}(1 - A_{wz}/A_g) + F_{cw}A_{wz}/A_g$

The gross area of the compression flange is

$A_g = 16(1) = 16 \text{ in}^2$

The weld-affected area of the compression flange is

$A_{wz} = 2.375 \text{ in}^2$

$F_{cf}/\Omega = [F_{co}(1 - A_{wz}/A_g) + F_{cw}A_{wz}/A_g]/\Omega$

$F_{cf}/\Omega = [10.3(1 - 2.375/16) + 10.3(2.375)/16] = 13.0$ ksi

Section B.5.5.1 addresses the web. The slenderness ratio of the web is

$b/t = (50 - 2)/0.375 = 128$

$c_c = -22.9 + 1 = -21.9$

$c_o = 27.1 - 1 = 26.9$

$c_o/c_c = 26.9/-21.9 = -1.23$

$m = 1.3/(1 - c_o/c_c) = 1.3/(1-(-1.23)) = 0.58$

For the unwelded portion of the web

$$S_2 = \frac{k_1 B_{br}}{mD_{br}} = \frac{0.5(46.1)}{(0.58)(0.376)} = 106$$

$b/t = 128 > 106 = S_2$,

$$\text{so } F_{bo} = \frac{k_2\sqrt{B_{br}E}}{mb/t} = \frac{2.04\sqrt{(46.1)(10{,}400)}}{(0.58)(128)} = 19.0 \text{ ksi}$$

$F_{bo}/\Omega = 19.0/1.85 = 10.3$ ksi

For the welded portion of the web

$$S_2 = \frac{k_1 B_{br}}{mD_{br}} = \frac{0.5(34.1)}{(0.58)(0.240)} = 122$$

$b/t = 128 > 122 = S_2$,

$$\text{so } F_{bo} = \frac{k_2\sqrt{B_{br}E}}{mb/t} = \frac{2.04\sqrt{(34.1)(10{,}400)}}{(0.58)(128)} = 16.4 \text{ ksi}$$

$F_{bw}/\Omega = 16.4/1.85 = 8.8$ ksi

Section B.5.5 provides the strength of the web in compression as

$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw}A_{wzc}/A_{gc}$

The gross area of the web in compression is

$A_g = 0.375(22.9 - 1) = 8.21 \text{ in}^2$

The weld-affected area of the web in compression is

$A_{wz} = (1)(0.375) = 0.375 \text{ in}^2$

$F_b/\Omega = [F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw}A_{wzc}/A_{gc}]/\Omega$

$F_b/\Omega = [10.3(1 - 0.375/8.21) + 8.8(0.375)/8.21] = 10.2$ ksi

Section F.8.3 provides the weighted average strength of the elements.

The moment of inertia of the flanges is

$I_f = (12)(1)^3/12 + (16)(1)^3/12 + (16)(1)(22.9 - 0.5)^2 + (12)(1)(27.1 - 0.5)^2 = 16{,}521 \text{ in}^4$

The moment of inertia of the web is

$I_w = (0.375)(48)^3/12 + (0.375)(48)(27.1 - 25)^2 = 3535 \text{ in}^4$

For compression,

$M_{nc} = F_{cf}I_f/c_{cf} + F_{cw}I_w/c_{cw}$

$M_{nc}/\Omega = (13.0)(16521)/(22.9 - 0.5) + (10.2)(3535)/22.9 - 1) = 11{,}235$ in-k.

For tension,

$$M_{nt} = F_{tf} I_f / c_{tf} + F_{tw} I_w / c_{tw}$$

$$M_{nt}/\Omega = (15.5)(16521)/(27.1) + (21.5)(3535)/27.1 - 1) = 12{,}360 \text{ in-k.}$$

The allowable moments are:
For lateral-torsional buckling: M_n/Ω =10,970 in-k
For local buckling: M_n/Ω =11,235 in-k
For tension: M_n/Ω =12,360 in-k

The least of these is 10,970 in-k from lateral torsional buckling.

Allowable moment based on fatigue per Appendix 3

Figure 3.1 detail 4 is similar to this example. Table 3.1 indicates that this detail is fatigue category B. Section 3.2 requires that for constant amplitude loading the applied stress range S_{ra} be less than the allowable stress range S_{rd}:

$$S_{ra} < S_{rd} = C_f N^{-1/m}$$

For category B, Table 3.2 gives C_f = 130 ksi and m = 4.84, so

$$S_{rd} = (130 \text{ ksi})/(500{,}000)^{1/4.84} = 8.6 \text{ ksi}$$

Assuming that the dead load stresses are negligible, the maximum stress equals the stress range. The section modulus corresponding to the weld on the tension flange is

$$S_w = 20{,}132/(27.1 - 1.0) = 771 \text{ in}^3$$

The tensile moment for fatigue M_f for the tensile stress range is

$$M_f = S_{rd} S_w = (8.6 \text{ k/in}^2)(771 \text{ in}^3) = 6630 \text{ in-k}$$

If variable amplitude loading occurred, an equivalent stress range would be calculated to compare to the allowable stress range. For example, if the loading were

100,000 cycles	9.5 ksi stress range
50,000 cycles	10.0 ksi stress range
350,000 cycles	7.1 ksi stress range
500,000 cycles	at various stress ranges

Section 3.3 provides the equivalent stress range S_{re} for variable amplitude loading:

$$S_{re} = [(100/500)9.5^{4.84} + (50/500)10.0^{4.84} + (350/500)7.1^{4.84}]^{1/4.84} = 8.2 \text{ ksi} < 8.6 \text{ ksi}$$

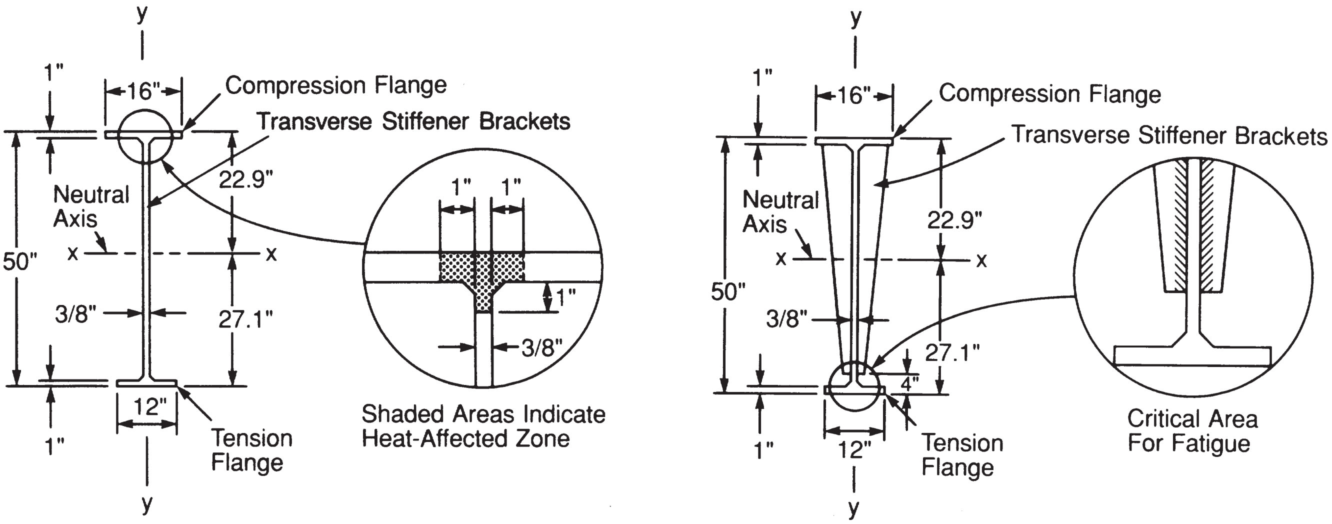
So this variable amplitude loading does not exceed the allowable stress range.

Selection of allowable moment

Comparing the allowable static (10,970 in-k) and fatigue (6630 in-k) moments, the allowable moment is 6630 in-k from fatigue.

NOTES: If the shape of the moment diagram is known the lateral-torsional buckling strength could be determined more precisely by using the larger, more accurate value of r_{ye}, computed according to Section F.2.2.

Example 17
WELDED BEAM SUBJECT TO FATIGUE
Illustrating Sections 3.1 and 3.2



Welded Beam of Alloy 5456-H321

(a)

Welded Beam of Alloy 5456-H321

(b)

Figure 17

GIVEN:

Same as Example 16 except that the number of load cycles = 500,000.

REQUIRED:

Allowable bending moment range for fatigue loading of the beams shown in Figure 17.

SOLUTION:

a) Beam with no transverse brackets

Specification Figure 3.1 Example 4 is a girder with continuous welds attaching web and flange, similar to that shown in Figure 17a. The stress category is selected from Table 3.1. The category for a built-up member (see general condition in left column) with continuous weld parallel to the direction of stress for example numbers 3, 4, and 5 (right column) is B.

Section 3.2 requires for constant amplitude loading that the applied stress range S_{ra} shall not exceed the allowable stress range S_{rd}

$$S_{rd} = C_f N^{-1/m}$$

Where, for Stress Category B,

$$C_f = 130 \text{ ksi and } m = 4.84$$

for the number of cycles, $N = 500{,}000$,

$$S_{rd} = (130)(500{,}000)^{-1/4.84} = 8.6 \text{ ksi}$$

The section modulus, S_w corresponding to the weld location on the tension flange is:

$$S_w = 20{,}132/(27.1-1.0) = 771 \text{ in}^3$$

The allowable moment range for fatigue ΔM is calculated for a tensile stress range at the web.

$$\Delta M = S_{rd} S_w = 8.6\ (771) = 6630 \text{ in-k}$$

If variable amplitude loading occurred, an equivalent stress range would be calculated and compared to the allowable stress range. For example, if the loading were

100,000 cycles	9.5 ksi stress range
50,000 cycles	10.0 ksi stress range
350,000 cycles	7.1 ksi stress range
500,000 cycles	at various stress ranges

Section 3.3 requires that the equivalent stress range S_{re} shall not exceed the allowable stress range S_{rd}

$$S_{re} = [(100/500)9.5^{4.84} + (50/500)10^{4.84} + (350/500)7.1^{4.84}]^{1/4.84}$$

$$S_{re} = 8.2 \text{ ksi} < 8.6 \text{ ksi} = S_{rd}$$

So this variable amplitude loading does not exceed the allowable stress range.

b) Beam with transverse brackets

Specification Figure 3.1 Example 6 is a girder with a similar detail at the bottom of the stiffener to that shown in Figure 17b. The category corresponding to Example 6 is C.

Section 3.2 requires for constant amplitude loading that the applied stress range S_{ra} shall not exceed the allowable stress range S_{rd}

$$S_{rd} = C_f N^{-1/\mathrm{m}}$$

Where, for stress category C,

$C_f = 278$ ksi and $m = 3.64$

for the number of cycles, $N = 500{,}000$,

$$S_{rd} = (278)(500{,}000)^{-1/3.64} = 7.6 \text{ ksi}$$

The section modulus at the bottom end of the stiffener is:

$$S_w = (20{,}132)/(27.1 - 4.0) = 872 \text{ in}^3$$

The allowable moment range for fatigue ΔM is calculated for a tensile stress range at the end of the stiffener.

$$\Delta M = (7.6 \text{ k/in}^2)(872 \text{ in}^3) = 6630 \text{ in-k}$$

Example 18
PIPE IN BENDING
Illustrating Section F.6

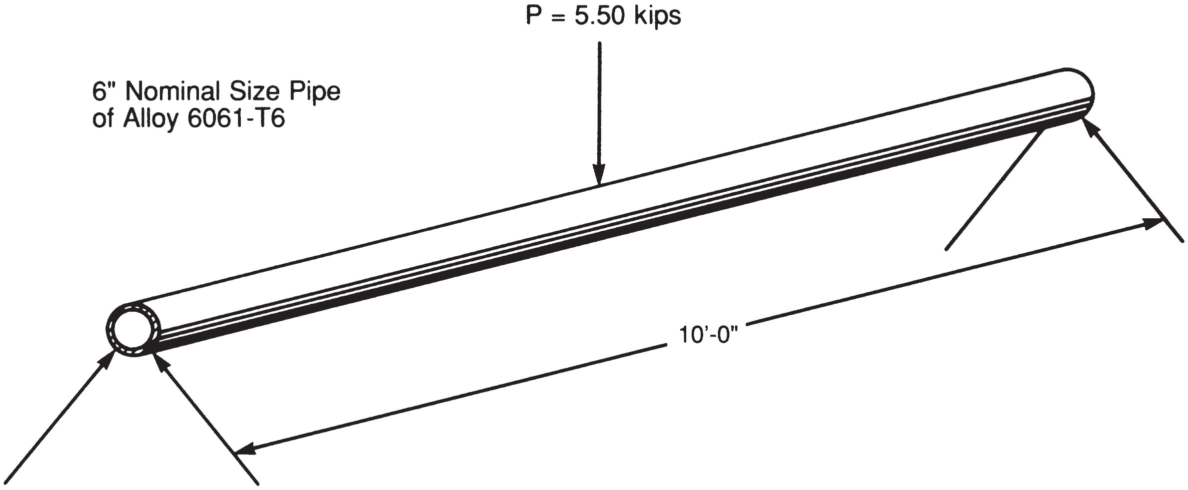


Figure 18

GIVEN:

1. Concentrated load of 5.5 k (5,500 lb) at mid-span.
2. Span: 10 ft, simply supported.
3. Alloy: 6061-T6.
4. Structure type: building

REQUIRED:

Wall thickness of thinnest 6 in. pipe with an allowable load that exceeds the concentrated load.

SOLUTION:

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure of building-type structures. Section F.6 addresses round tubes in flexure. Allowable stresses for 6061-T6 are given in Part VI Table 2-19 are used below.

Section F.6.1 addresses the limit states of yielding and rupture.

For the limit state of compressive yielding, the allowable stress is

$1.17F_{ty}/1.65 = 1.17(35)/1.65 = 24.8$ ksi

For the limit state of tensile yielding, the allowable stress is

$1.17F_{ty}/1.65 = 1.17(35)/1.65 = 24.8$ ksi

For the limit state of tensile rupture, the allowable stress is

$1.24F_{tu}/[(1.95)(k_t)] = 1.24(38)/1.95/1.0 = 24.2$ ksi

From Part VI Beam Formulas Case 1, a simply supported beam with a concentrated load P at center, the maximum moment is

$M = PL/4 = (5.5)(10)(12)/4 = 165$ in-k

$S = M/(F/\Omega) = (165 \text{ in-k})/(24.4 \text{ ksi}) = 6.82 \text{ in}^3$, trial section modulus

Part V Table 22 shows that a 6.625 in. OD Schedule 40 pipe with a wall thickness of 0.280 in. and section modulus of 8.50 in^3 is the thinnest 6 in. pipe with a section modulus greater than 6.82 in^3.

$R_b/t = (6.625 - 0.280)/2/0.280 = 11.3 < 55 = S_1$

So $F_b/\Omega = 39.3 - 2.702(R_b/t)^{1/2} = 30.2 \text{ ksi} > 24.2$ ksi

The trial beam is therefore satisfactory; use Schedule 40 pipe.

Example 19
RECTANGULAR BAR IN BENDING
Illustrating Section F.4

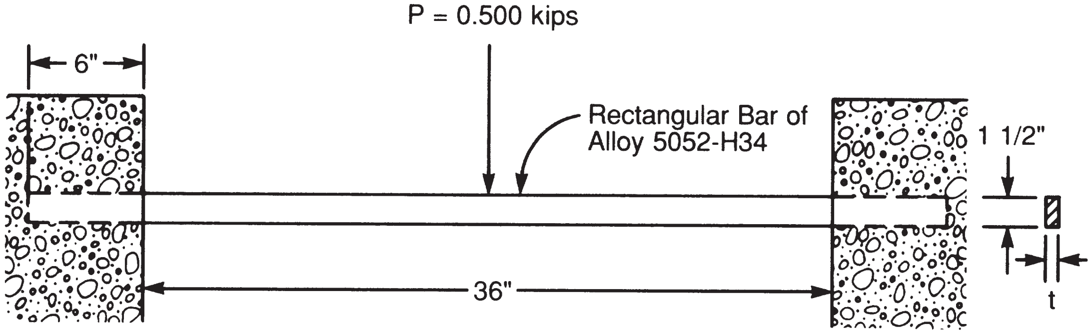


Figure 19

GIVEN:

1. Beam section: 1.50 in. deep rectangular bar.
2. Load 0.500 k (500 lb) at mid-span.
3. Span: 36 in.
4. Ends of beam restrained against rotation and translation, lateral support at ends only.
5. Alloy: 5052-H34.
6. Structure type: building

REQUIRED:

The thinnest standard bar with an allowable load that exceeds the applied load.

SOLUTION:

From Part V Table 28 provides section properties for a rectangle

Try a 1/4 in. thick bar

$A = 0.25\ (1.50) = 0.375\ \text{in}^2$

$I_x = (0.25)(1.5)^3/12 = 0.070\ \text{in}^4$

Since this section is symmetric about the x-axis,

$c = d/2 = 1.5/2 = 0.75$ in.

From Part VI, Beam Formulas Case 26, concentrated load P at center, the maximum moment is

$M = PL/8 = (0.5)(36)/8 = 2.25$ in-k

The flexural stress at the extreme fiber is

$f = Mc/I = (2.25)(0.75)/(0.070) = 24.1$ ksi

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure of building-type structures. Section F.4 addresses flexure of solid rectangular shapes. Part VI Table 2-10 gives allowable stresses for 5052-H34.

Section F.4.1 addresses the limit states of yielding and rupture:

For the limit state of compressive yielding, the allowable stress is

$1.3F_{cy}/1.65 = 1.3(24)/1.65 = 18.9$ ksi

For the limit state of tensile yielding, the allowable stress is

$1.3F_{ty}/1.65 = 1.3(26)/1.65 = 20.5$ ksi

For the limit state of tensile rupture, the allowable stress is

$1.42F_{tu}/[(1.95)(k_t)] = 1.42(34)/1.95/1.0 = 24.8$ ksi

Since the least of these allowable stresses is 18.9 ksi < 24.1 ksi, a thicker bar is needed.

Try a 3/8 in. thick bar

$A = 0.563\ \text{in}^2$

$I_x = 0.105\ \text{in}^4$

$f = Mc/I = (2.25)(0.75)/(0.105) = 16\ \text{ksi} < 18.9\ \text{ksi}$

Now check the limit state of lateral-torsional buckling addressed in Section F.4.2. Conservatively using $C_b = 1.0$,

$$S = \frac{d}{t}\sqrt{\frac{L_b}{C_b d}} = \frac{1.5}{0.375}\sqrt{\frac{36}{(1)(1.5)}} = 19.6 < S_2 = 36$$

$$F/\Omega = 26.7 - 0.495(19.6) = 17.0 \text{ ksi}$$

The section modulus of a 5⁄16 in. wide bar would be 5⁄6 of the section modulus of a 3⁄8 in. wide bar. Since the stress $f = 16$ ksi is more than 5⁄6 of the allowable of 17.0 ksi, a 5⁄16 in. bar will not be satisfy the requirements even at the stress permitted for a 3⁄8 in. bar.

Use a 3⁄8 in. thick bar.

Example 20
RECTANGULAR TUBE IN BENDING
Illustrating Sections F.3 and F.8

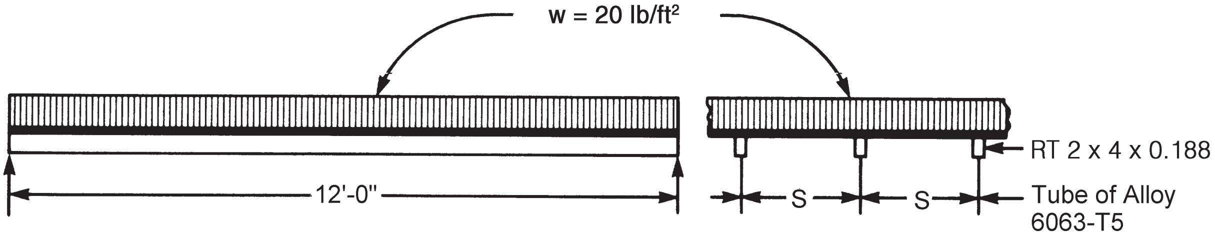


Figure 20

GIVEN:

1. 4 in. × 2 in rectangular tube with 0.188 in. wall (RT 2 × 4 × 0.188)
2. Load: 20 lb/ft² total live and dead loads.
3. 12 ft simple span, laterally unsupported.
4. Alloy: 6063-T5.
5. Structure type: building

REQUIRED:

The maximum allowable spacing of the beams.

SOLUTION:

Part V Table 24 provides section properties for rectangular tubes:

$$I_x = 4.23 \text{ in}^4,\ S_x = 2.11 \text{ in}^3,\ I_y = 1.37 \text{ in}^4,\ J = 3.19 \text{ in}^4$$

The slenderness ratio of the flange is
$b/t = (2 - 2(0.188))/0.188 = 8.6$

The slenderness ratio of the web is
$b/t = (4 - 2(0.188))/0.188 = 19.3$

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure of building-type structures. Section F.3 addresses flexure of tubular shapes. Because the tubes are bent about their major axis, they are subject to lateral-torsional buckling and must meet the requirements of both Section F.3 and F.8. Part VI Table 2-20 gives allowable stresses for 6063-T5.

Section F.8.1 addresses tension.

Section F.8.1.1 addresses elements in uniform tension (the flange), for which $F_b/\Omega = 9.7$ ksi,

Section F.8.1.2 addresses elements in flexure (the web), for which $F_b/\Omega = 12.6$ ksi.

Conservatively use the lesser of these in lieu of the weighted average tensile strength given in Section F.8.3.

Section F.8.2 addresses compression.

Section B.5.4.2 addresses the flange;
$b/t = 8.6 < 25.6 = S_1$, so $F_b/\Omega = 9.7$ ksi

Section B.5.5.1 addresses the web;
$b/t = 19.3 < 62.9 = S_1$, so $F_b/\Omega = 12.6$ ksi

Conservatively use the lesser of these in lieu of the weighted average compressive strength given in Section F.8.3.

Section F.3.1 addresses lateral-torsional buckling. Conservatively using $C_b = 1.0$,

$$S = \frac{2L_bS_c}{C_b\sqrt{I_yJ}} = \frac{2(144)(2.11)}{\sqrt{1.37(3.19)}} = 291 < S_2 = 3823$$

$F_b/\Omega = 10.5 - 0.070(291)^{1/2} = 9.3$ ksi

The lowest allowable stress is 9.3 ksi

$M = S_cF_b/\Omega = 2.11(9.3) = 19.6$ in-k

Part V Beam Formulas Case 6, simply supported beam with uniform load, has a maximum moment of

$M = WL/8$, which can be written as

$W = 8M/L$

$W_1 = 8(19.6)/144 = 1.09$ k = allowable total load for flexure

Section G.2 addresses web shear

$b/t = (4 - 2(0.188))/0.188 = 19.3 < S_1 = 43.6$

$F_s/\Omega = 5.8$ ksi

Web area

$A = 2 \times 0.188 \times 4 = 1.5 \text{ in}^2$

$V = (F_s/\Omega)\, A = 5.8 \times 1.5 = 8.7 \text{ k}$

$W_2 = 2V = 2 \times 8.7 = 17.4$ k = allowable load for shear.

Since $W_1 < W_2$, lateral-torsional buckling controls

$W = W_1 = 1.09$ k, the total allowable load per beam.

The allowable spacing can now be determined from the given unit load of 20 lb/ft^2 or 0.020 k/ft^2

$$\text{Spacing} = (1.09 \text{ k})/[0.020 \text{ k/ft}^2)(12 \text{ ft})] = 4.54 \text{ ft o.c.}$$
$$= 54 \text{ in.}$$

The center to center spacing of the beams should therefore not exceed 54 in.

Example 21
I-BEAM IN BENDING
Illustrating Section F.8

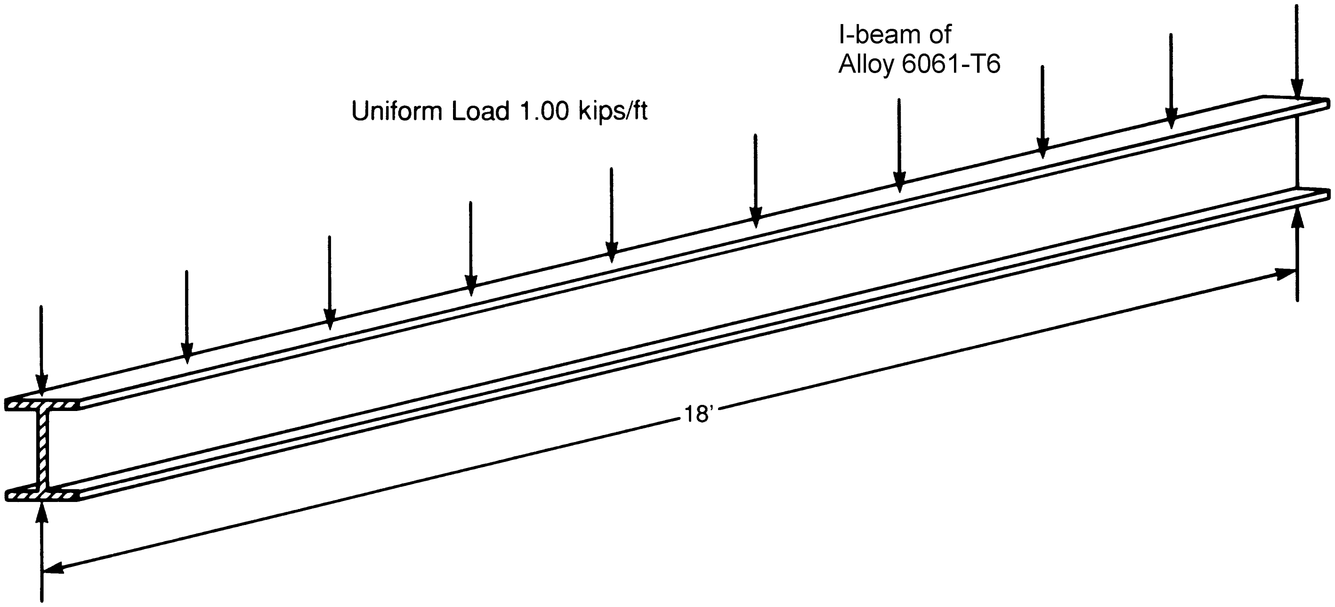


Figure 21

GIVEN:

1. Uniform load: 1.0 k/ft (1,000 lb/ft) including dead load.
2. Span: 18 ft, simply supported.
3. Compression flange is adequately supported laterally.
4. Alloy: 6061-T6.
5. Structure type: building

REQUIRED:

Size of lightest Aluminum Association standard I-beam with an allowable load that exceeds 1.0 k/ft.

SOLUTION:

Part VI Beam Formulas Case 6 gives the total load W as

$$W = wL = 1.0 \times 18.0 = 18.0 \text{ k}$$

Part VI Table 4-2 indicates that an I 10 × 8.65 will support 19.69 k at a 17 ft span; therefore, it may be the desired beam. The allowable load for an 18 ft span is not tabulated, but it can be determined as follows:

Maximum bending moment,

$$M = WL/8 = (18 \text{ k})(18 \text{ ft})(12 \text{ in/ft})/8 = 486 \text{ in-k}$$

Part V, Table 8, gives the section properties:

$S_x = 26.4$ in^3, $b = 6$ in., $t_w = 0.25$ in., $t_f = 0.41$ in.

The flange's slenderness ratio is
$b/t = (6 - 0.25)/2/0.41 = 7.0$

The web's slenderness ratio is
$b/t = (10.0 - 2(0.41))/0.25 = 36.7$

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure of building-type structures. Because the compression flange is laterally supported, the beam is not subject to lateral-torsional buckling. For open shapes not subject to lateral-torsional buckling, Section F.2 requires that Section F.8 be used to determine the flexural strength. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

Section F.8 addresses elements of flexural members.

a) Section F.8.1 addresses tension.

Section F.8.1.1 addresses elements in uniform tension (the flange), for which $F_b/\Omega = 19.5$ ksi,

Section F.8.1.2 addresses elements in flexure (the web), for which $F_b/\Omega = 27.6$ ksi.

b) Section F.8.2 addresses compression.

Section B.5.4.1 addresses the flange; $b/t = 7.0 > 6.7 = S_1$, so $F_b/\Omega = 27.3 - 0.91(7.0) = 20.9$ ksi

Section B.5.5.1 addresses the web; $b/t = 36.7 < 49.3 = S_1$, so $F_b/\Omega = 27.6$ ksi

The least of these allowable stresses is 19.5 ksi.

$f = M/S = 486/(26.4) = 18.4 \text{ k/in}^2 < 19.5$ ksi

Since the calculated stress, 18.4 ksi, is less than the allowable tensile stress of 19.5 ksi and the allowable compressive stress of 20.9 ksi, the trial beam is satisfactory.

NOTE: Section G.2 should be also be checked. It will be more likely to govern for short, heavily loaded beams.

Example 22
UNSYMMETRIC BEAM IN BENDING
Illustrating Sections B.5.4.1, B.5.4.2, B.5.4.3, B.5.5.1, and F.8

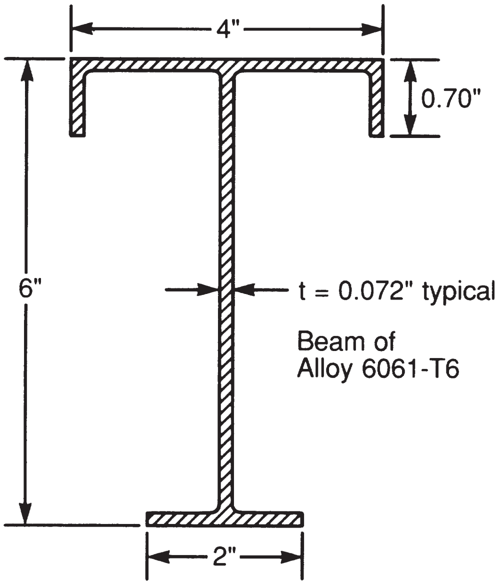


Figure 22

GIVEN:

1. Beam of cross section shown in Figure 22
2. Continuous lateral support of compression (top) flange
3. Alloy: 6061-T6
4. Structure type: building

REQUIRED:

Allowable bending moment.

SOLUTION:

The section properties are computed as shown in example 16 with the following results:

$c_t = 3.70$ in. $\qquad I_x = 5.15$ in^4

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure of building-type structures. Because the compression flange is laterally supported, the beam is not subject to lateral-torsional buckling. For open shapes not subject to lateral-torsional buckling, Section F.2 requires that Section F.8 be used to determine the flexural strength. Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

Section F.8 addresses elements of flexural members.

a) Section F.8.1 addresses tension.

Section F.8.1.1 addresses elements in uniform tension (the flange), for which $F_b\ \Omega = 19.5$ ksi,

The allowable moment for tension is
$M_1 = FI/c_t = (19.5)(5.15)/3.70 = 27.1$ in-k

Section F.8.1.2 addresses elements in flexure (the web), for which $F_b/\Omega = 27.6$ ksi. Conservatively use the lesser of the allowable tensile stresses for the web and flange.

b) Section F.8.2 addresses compression.

Section B.5.5.1 addresses elements in flexure (the web). The web slenderness is

$b/t = (6 - 2(0.072))/0.072 = 81.3$

$c_c = -(6 - 3.7) = -2.3$; $c_o = 3.7$

$c_o/c_c = 3.7/(-2.3) = -1.6 < -1$, so $m = 1.3/(1 - c_o/c_c)$
$= 1.3/(1 - (3.7/-2.3)) = 0.50$

$S_1 = (B_{br} - 1.3F_{cy})/(mD_{br})$
$= (66.8 - 1.3(35))/(0.5(0.665) = 64.1$

$S_2 = k_1B_{br}/(mD_{br}) = 0.5(66.8)/[(0.5)(0.665)] = 100.5$

Since $S_1 = 64.1 < 81.3 < 100.5 = S_2$,

$F_b/\Omega = [B_{br} - mD_{br}(b/t)]/\ \Omega$
$= (66.8 - 0.5(0.665)(81.3))/1.65 = 24.1$ ksi

The allowable moment based on web compression is

$M_2 = (24.1)(5.15)/(6 - 3.70 - 0.072) = 55.7$ in-k

The distance from the neutral axis to the centroid of the flange stiffener is

$c = 6 - 3.70 - 0.072 - 0.5(0.7 - 0.072) = 1.91$ in.

The stiffener can be treated as an element in uniform compression if the distance from the neutral axis to the centroid of the stiffener is greater than 75% of the distance from the neutral axis to the extreme fiber.

The distance from the neutral axis to the extreme fiber $c = 6 - 3.70 = 2.3$ in.; $0.75(2.3) = 1.72$ in. < 1.91 in., so treat the stiffener as an element in uniform compression.

Section B.5.4.1 addresses elements in uniform compression supported on one edge. The stiffener's slenderness is

$b/t = (0.70 - 0.072)/0.072 = 8.7$, which is between 6.7 $= S_1$ and $10.5 = S_2$, so $F_b/\Omega = 27.3 - 0.91(8.7)$
$= 19.4$ ksi

The allowable moment based on stiffener compression is $M_3 = (19.4)(5.15)/(6 - 3.70 - 0.072) = 44.8$ in-k

Section B.5.4.3 addresses elements supported on one edge and with a stiffener at the other edge.

The flange element width is $b = (4 - 3(0.072))/2 = 1.89$ in.

The depth of the stiffener is $D_s = 0.70 - 0.072 = 0.628$ in.

$D_s/b = 0.628/1.89 = 0.33 < 0.8$, so Section B.5.4.3 applies.

$$S_e = 1.28\sqrt{\frac{E}{F_{cy}}} = 1.28\sqrt{\frac{10{,}100}{35}} = 21.7$$

$b/t = 1.89/0.072 = 26.25$

$$r_s = \frac{d_s \sin\theta}{\sqrt{3}} = \frac{0.7 - 0.072}{\sqrt{3}} = 0.363$$

$2S_e = 43.5 > 26.25 = b/t > 21.7 = S_e$, so

$$\rho_{st} = \frac{r_s}{1.5t\left(\frac{b/t}{S_e} + 3\right)} = \frac{0.363}{1.5(0.072)\left(\frac{26.25}{21.7} + 3\right)}$$

$$= 0.797 \le 1.0$$

F_{UT}/Ω = allowable stress for flange as if supported on one edge per B.5.4.1

$b/t = 26.25 > 10.5 = S_2$, so

$F_{UT}/\Omega = 186/26.25 = 7.1$ ksi

F_{ST}/Ω = allowable stress for flange as supported on both edges per B.5.4.2

$S_1 = 20.8 < b/t = 26.25 < 33 = S_2$

$F_{ST}/\Omega = 27.3 - 0.291\ (b/t) = 27.3 - 0.291(26.25)$

$F_{ST}/\Omega = 19.7$ ksi

$F_c/\Omega = F_{UT}/\Omega + (F_{ST}/\Omega - F_{UT}/\Omega)\rho_{ST} \le F_{ST}$

$F_c/\Omega = 7.1 + (19.7 - 7.1)\ (0.797) = 17.1$ ksi

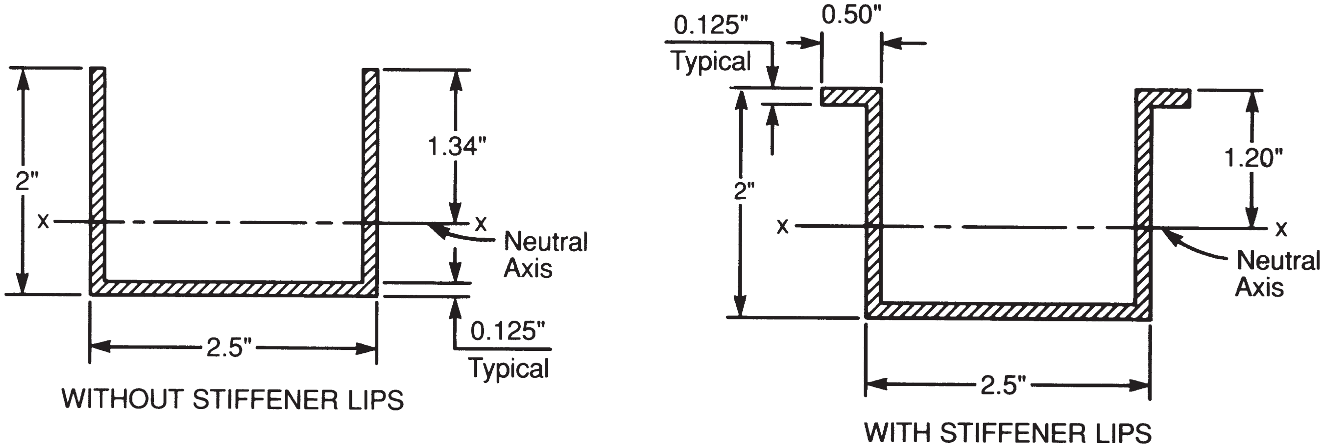
$M_4 = (17.1)(5.15)/(6 - 3.70 - (0.072/2)) = 38.9$ in-k

The smallest of the allowable moments M_1 thru M_4 is M_1, so the allowable moment is

$M = 27.1$ in-k

NOTE: Shear stress would be checked using Section G.2.

Example 23
CHANNEL IN BENDING
Illustrating Sections B.5.4.1, B.5.5.1, B.5.5.2, and F.8



WITHOUT STIFFENER LIPS

WITH STIFFENER LIPS

Channel Beams of Alloy 6063-T6

Figure 23

GIVEN:

1. 2.5 in. × 2 in. × 0.125 in. channels as shown in Figure 23
2. Alloy: 6063-T6
3. Structure type: building

REQUIRED:

The allowable positive bending moment about the *X*-*X* axis for each channel shown in Figure 23

SOLUTION:

Part I, channel without stiffener lips:

The section properties are computed using the method shown in example 16 with the following results:

$c = 1.34$ in. to the top fiber

$I = 0.325\ \text{in}^4$

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure of building-type structures. Because the channel is bent about its weak axis, it is not subject to lateral-torsional buckling. For open shapes not subject to lateral-torsional buckling, Section F.2 requires that Section F.8 be used to determine the flexural strength. Allowable stresses for 6063-T6 given in Part VI Table 2-21 are used below.

Section F.8 addresses elements of flexural members.

a) Section F.8.1 addresses tension.

Section F.8.1.1 addresses elements in uniform tension (the flange), for which $F_b/\Omega = 15.2$ ksi,

The allowable moment for tension in the flange is $M_1 = FI/c_t = (15.2)(0.325)/(2 - 1.34) = 7.5$ in-k

Section F.8.1.2 addresses elements in flexure (the web), for which $F_b/\Omega = 19.7$ ksi.

The allowable moment for tension in the web is $M_2 = FI/c_t = (19.7)(0.325)/(2 - 1.34 - 0.125) = 12.0$ in-k

b) Section F.8.2 addresses compression.

Section B.5.5.2 addresses elements in flexure (the web) with the tension edge supported and the compression edge free. The web slenderness is

$b/t = (2 - 0.125)/0.125 = 15$, which is between $S_1 = 10.2$ and $S_2 = 23$ so $F_b/\Omega = 27.9 - 0.81(b/t) = 15.7$ ksi

The allowable moment based on web compression is $M_3 = (15.7)(0.325)/1.34 = 3.81$ in-k

The least of the allowable moments is $M_3 = 3.81$ in-k, so 3.81 in-k is the allowable moment.

Part II, channel with stiffener lips:

The section properties are computed using the method shown in example 16 with the following results:

$c = 1.20$ in. to the top fiber

$I = 0.461\ \text{in}^4$

a) Section F.8.1 addresses tension.

Section F.8.1.1 addresses elements in uniform tension (the flange), for which $F_b/\Omega = 15.2$ ksi,

The allowable moment for tension in the flange is $M_1 = FI/c_t = (15.2)(0.461)/(2 - 1.20) = 8.8$ in-k

Section F.8.1.2 addresses elements in flexure (the web), for which $F_b/\Omega = 19.7$ ksi.

The allowable moment for tension in the web is $M_2 = FI/c_t = (19.7)(0.461)/(2 - 1.20 - 0.125) = 13.5$ in-k

b) Section F.8.2 addresses compression.

Section B.5.4.1 addresses elements in uniform compression supported on one edge (the lip). The lip slenderness is

$b/t = (0.50 - 0.125)/0.125 = 3$, so $F_b/\Omega = 15.2$ ksi

The allowable moment based on lip compression is $M_3 = (15.2)(0.461)/1.20 = 5.8$ in-k

Section B.5.5.1 addresses elements in flexure (the web) supported on both edges. The web slenderness is

$b/t = (2 - 2(0.125))/0.125 = 14$

$c_c = -1.20$

$c_o = 2 - 1.20 = 0.8$

$c_o/c_c = 0.8/(-1.2) = -0.67$

$m = 1.15 + c_o/(2c_c) = 1.15 + 0.5(-0.67) = 0.82$

Since $b/t = 14 < S_1 = 54.9$, $F_b/\Omega = 19.7$ ksi

The allowable moment based on web compression is $M_4 = (19.7)(0.461)/(1.20 - 0.125) = 8.4$ in-k.

The least of the allowable moments is $M_3 = 5.8$ in-k, so 5.8 in-k is the allowable moment.

NOTES: The use of Section B.5.5.1 assumes that the lip provides lateral support at the top of the web. Section F.8.2.3 may be used to determine the local buckling strength more precisely and check this assumption.

Example 24
ALLOWABLE WEB STRESS IN A WELDED BEAM
Illustrating Section B.5.5.1

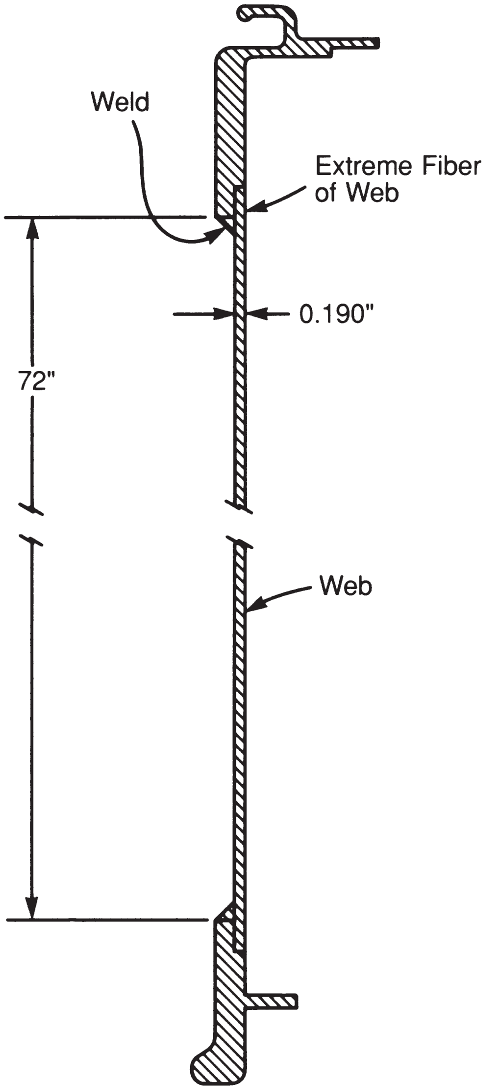


Figure 24

GIVEN:

1. Beam cross section as shown in Figure 24
2. Alloy of web: 6061-T6
3. Structure type: building

REQUIRED:

Allowable compressive bending stress at the extreme fiber of web.

SOLUTION:

Assume that the neutral axis is approximately at the mid-height of the web. For the web,

$$b/t = 72/0.190 = 379$$

Section B.5.5 states that for elements in flexure, the stress corresponding to the flexural compression strength is

$$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw}A_{wzc}/A_{gc}$$

where

F_{bo} = stress corresponding to the flexural compression strength calculated using Section B.5.5.1 for an element if no part of the cross section were weld-affected. Using Part VI Table 2-18 for unwelded allowable stresses, since $b/t = 379 > 77 = S_2$:

$F_{bo}/\Omega = 1563/(b/t) = 1563/379 = 4.1$ ksi

F_{bw} = stress corresponding to the flexural compression strength calculated using Section B.5.5.1 for an element if the entire cross section were weld-affected. Since the web is less than 0.375″ thick, regardless of the filler used, use Part VI Table 2-19W for the welded allowable stresses. Since $b/t = 379 > 123 = S_2$:

$F_{bw}/\Omega = 982/(b/t) = 982/379 = 2.6$ ksi

A_{wzc} = cross sectional area of the weld-affected zone in compression

$A_{wzc} = (1\text{ in.})(0.190\text{ in.}) = 0.19\text{ in}^2$

A_{gc} = gross cross sectional area of the element in compression.

$A_{gc} = (72\text{ in.})(0.190\text{ in.})/2 = 6.84\text{ in}^2$

$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw}\,A_{wzc}/A_{gc}$

$F_b/\Omega = (4.1)(1 - 0.19/6.84) + (2.6)(0.19)/6.84 = 4.1$ ksi

NOTES: Lateral-torsional buckling must also be checked using Section F.2.

Filler metal for welds should be selected from *Specification* Table M.9.1.

Example 25
ALLOWABLE WEB STRESS IN A WELDED BEAM WITH STIFFENED WEB
Illustrating Section B.5.5.3

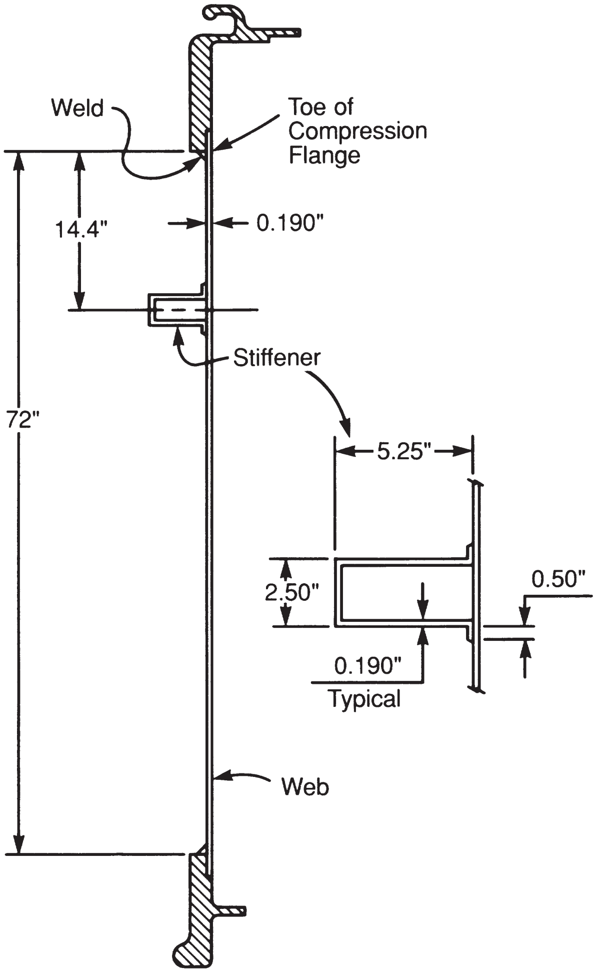


Figure 25

GIVEN:

1. Beam cross section as shown in Figure 25.
2. Neutral axis of beam is at mid-height of web.
3. Vertical stiffener spacing 10 ft o.c.
4. Alloy of web: 6061-T6.
5. Structure type: building

REQUIRED:

1. Allowable web stress at the toe of the compression flange.
2. Confirm adequacy of the longitudinal stiffener.

SOLUTION:

For the web, $b/t = 72/0.190 = 379$

Section B.5.5 states that for elements in flexure, the stress corresponding to the flexural compression strength is

$$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw}A_{wzc}/A_{gc}$$

where

F_{bo} = stress corresponding to the flexural compression strength calculated using Section B.5.5.3 for an element if no part of the cross section were weld-affected. Using Part VI Table 2-18 for unwelded allowable stresses, since $b/t = 379 > 173 = S_2$:

$F_{bo}/\Omega = 3502/(b/t) = 3502/379 = 9.2$ ksi

F_{bw} = stress corresponding to the flexural compression strength calculated using Section B.5.5.3 for an element if the entire cross section were weld-affected. Since the web is less than 0.375″ thick, regardless of the filler used, use Part VI Table 2-19W for the welded allowable stresses. Since $b/t = 379 > 275 = S_2$:

$F_{bw}/\Omega = 2201/(b/t) = 2201/379 = 5.8$ ksi

A_{wzc} = cross sectional area of the weld-affected zone in compression

$A_{wzc} = (1\text{ in.})(0.190\text{ in.}) = 0.19\text{ in}^2$

A_{gc} = gross cross sectional area of the element in compression.

$A_{gc} = (72\text{ in.})(0.190\text{ in.})/2 = 6.84\text{ in}^2$

$F_b = F_{bo}(1 - A_{wzc}/A_{gc}) + F_{bw}A_{wzc}/A_{gc}$

$F_b/\Omega = (9.2)(1 - 0.19/6.84) + (5.8)(0.19)/6.84 = 9.1$ ksi

Section B.5.5.3 provides requirements for the longitudinal stiffener

$\alpha_s = 3.5$, $b = 72$ in., $t = 0.190$ in., $f = 9.1$ ksi, $s = 10$ ft $= 120$ in.

$$A_L = 5.25 \times 2.50 - 5.06 \times 2.12 + 0.19 \times 1.00 = 2.59\text{ in}^2$$

$$I_L = \frac{0.02\alpha_s f t b^3}{E}\left[\left(1 + \frac{6A_L}{bt}\right)\left(\frac{s}{b}\right)^2 + 0.4\right]$$

$$= \frac{0.02(3.5)(9.1)(0.19)(72)^3}{10{,}100}\left[\left(1+\frac{6(2.59)}{72(0.19)}\right)\left(\frac{120}{72}\right)^2 + 0.4\right]$$

$I_L = 28.3\text{ in}^4$ = the required moment of inertia of the longitudinal stiffner.

Actual moment of inertia =

$$\tfrac{1}{3}(5.25^3 \times 2.50 - 5.06^3 \times 2.12 + 0.19^3 \times 1.00) = 29.0\text{ in}^4$$

The stiffener is therefore satisfactory.

The required distance from the toe of the compression flange to the centroid of the stiffener is

$0.4(72)/2 = 14.4$ in.

NOTES: The notes of example 24 also apply to this example.

Example 26
I-BEAM WITH WEB SHEAR CONTROLLING
Illustrating Sections F.8 and G.2

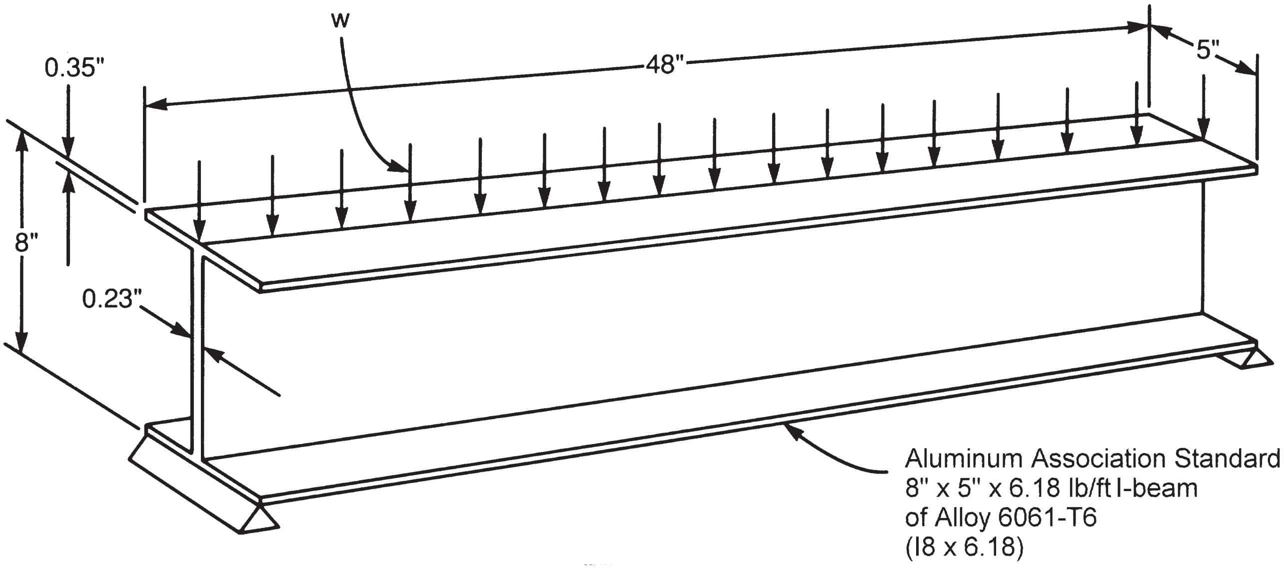


Figure 26

GIVEN:

1. 8 in. × 5 in. Aluminum Association standard I-beam weighing 6.18 lb/ft (I 8 × 6.18)
2. Span: 4 ft, simply supported at ends.
3. Compression flange continuously laterally supported.
4. Alloy: 6061-T6.
5. Structure type: building

REQUIRED:

Allowable uniform load.

SOLUTION:

From Part V, Table 8, Aluminum Association standard I-beams.

$d = 8.00$ in., $b = 5.00$ in., $A = 5.26$ in^2, $t_f = 0.35$ in.,
$t_w = 0.23$ in., $I_x = 59.7$ in^4, $S_x = 14.9$ in^3

For the flange, $b/t = (5.00 - 0.23)/2/0.35 = 6.8$

For the web, $b/t = (8.00 - 2(0.35))/0.23 = 31.7$

Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

Section F.1 establishes safety factors of 1.95 on tensile rupture and 1.65 on all other limit states for flexure of building-type structures. Because the compression flange is laterally supported, the beam is not subject to lateral-torsional buckling. For open shapes not subject to lateral-torsional buckling, Section F.2 requires that Section F.8 be used to determine the flexural strength.

Section F.8 addresses elements of flexural members.

a) Section F.8.1 addresses tension.

Section F.8.1.1 addresses elements in uniform tension (the flange), for which $F_b/\Omega = 19.5$ ksi,

Section F.8.1.2 addresses elements in flexure (the web), for which $F_b/\Omega = 27.6$ ksi.

b) Section F.8.2 addresses compression.

Section B.5.4.1 addresses the flange; $b/t = 6.8 > 6.7 = S_1$, so $F_b/\Omega = 27.3 - 0.91(6.8) = 21.1$ ksi

Section B.5.5.1 addresses the web; $b/t = 31.7 < 49.3 = S_1$, so $F_b/\Omega = 27.6$ ksi

The least of these allowable stresses is 19.5 ksi; tension controls bending.

Using an allowable stress of = 19.5 ksi
Allowable moment = $M = FS = 19.5 \times 14.9 = 291$ in-k

Section G.1 establishes a safety factor of 1.65 for shear of building-type structures. Section G.2 addresses shear in flat webs supported on both edges.

For $b/t = 31.7 < S_1 = 35.3$, $F_s/\Omega = 12.7$ ksi, allowable web shear stress.

Allowable shear $= (F_s/\Omega)A_w = (12.7 \text{ k/in}^2)(8)(0.23 \text{ in}^2) = 23.4$ k

From Part VI, Beam Formulas Case 6, for a simply supported beam with a uniform load,

$M = wL^2/8$, which can be written as $w_1 = 8M/L^2$, when w is unknown
$V = wL/2$, shear at end of beam. Rearranging, $w_2 = 2V/L$
$w_1 = 8M/L^2 = 8(291/12)/4^2 = 12.1$ k/ft for bending.
$w_2 = 2V/L = 2(23.4)/4 = 11.7$ k/ft for shear

Since w_1, the allowable load for bending, is greater than w_2, the allowable load for shear, the allowable load is $w_2 = 11.7$ k/ft.

NOTES: Section F.8.3, the weighted average flexural strength, could be used to determine a more precise and less conservative bending strength. Since shear controlled, however, using Section F.8.3 would not result in a greater allowable distributed load on the beam.

Example 27
WELDED CONNECTION
Illustrating Section J.2

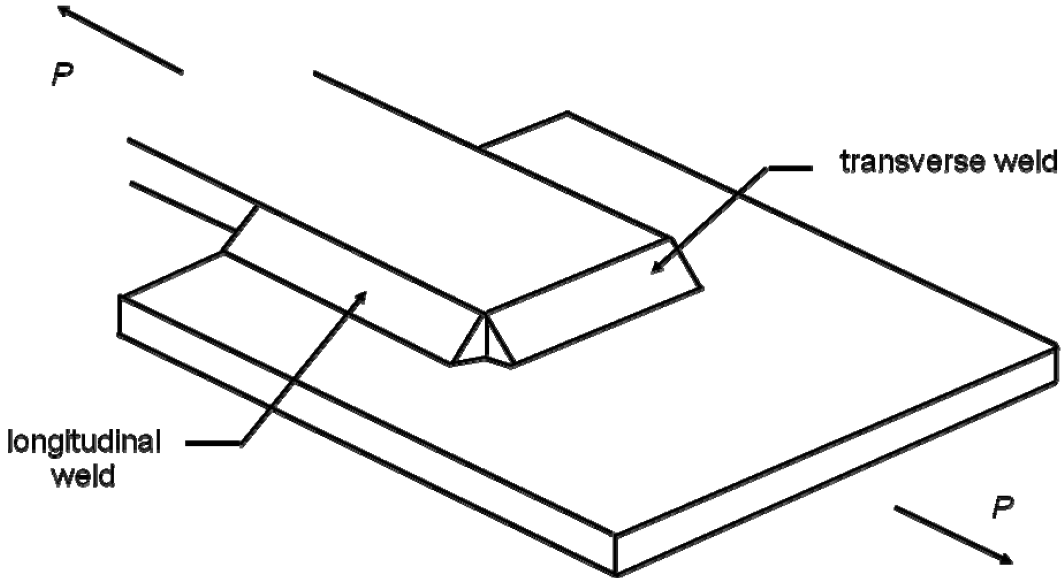


Figure 27

GIVEN:

1. Welded connection as shown in Figure 27
2. Longitudinal weld length 6 in. (each side), transverse weld length 4 in.
3. Weld size: $S_w = 3/8$ in. equal leg fillet
4. Base metal: 6061-T6
5. Filler alloy: 4043
6. Structure type: building

REQUIRED:

Determine the allowable force *P* on the connection.

SOLUTION:

Section J.2 establishes the allowable strength of welded connections as R_n/Ω, where $\Omega = 1.95$ for building-type structures.

Section J.2.2.1a) defines the effective throat of a fillet weld; the effective throat for an equal leg fillet is

$$e = 0.707S_w$$

$$e = 0.707(0.375 \text{ in.}) = 0.265 \text{ in.}$$

Section J.2.2.1b) defines the effective length L_{we}:

$$L_{we} = 2(6 \text{ in.}) + 4 \text{ in.} = 16 \text{ in.} > 4S_w = 4(0.375 \text{ in.})$$
$$= 1.5 \text{ in., so the full length of the weld is effective.}$$

The length of the end-loaded fillet weld is 6 in. < 100 (0.375 in.) = 37.5 in., which does not exceed the maximum effective length prescribed in Section J.2.2.1.

Section J.2.2.2 establishes the nominal strength of a fillet weld R_n as

$$R_n = F_{sw}L_{we}$$

where

F_{sw} is the lesser of:

a) The product of the weld filler's shear ultimate strength and the effective throat. The 4043 filler's shear ultimate strength is taken from Table J.2.1 as 11.5 ksi.

$$F_{sw} = (11.5 \text{ k/in}^2)(0.265 \text{ in.}) = 3.0 \text{ k/in.}$$

b) The product of the base metal's welded shear ultimate strength and the fillet size S_w. The 6061-T6 base metal welded shear ultimate strength is taken from Table A.3.5 as 15 ksi.

$$F_{sw} = (15 \text{ k/in}^2)(0.375 \text{ in.}) = 5.6 \text{ k/in.}$$

The lesser of these is 3.0 k/in., so

$$P = R_n/\Omega = F_{sw}L_{we}/\Omega = (3.0 \text{ k/in.})(16 \text{ in.})/1.95 = 24.6 \text{ k}$$

NOTES: The strength of aluminum fillet welds is usually governed by the strength of the filler alloy, as in this example. Therefore, the joint strength can be increased by using a stronger filler, such as 5356. Table M.9.1 shows which fillers may be used.

Example 28
OPEN SHAPE IN BENDING
Illustrating Sections F.1.1.1, F.2.1, F.2.2.1, F.2.2.3, and F.8.1.1

GIVEN:

1. Twin span curtainwall I-beam as shown in Figure 28d
2. Beam cross section and properties as given in Figure 28e
3. Uniform wind load of 26.3 lb/ft^2. Load must be applied as both a pressure (positive inward) and suction (negative) loading. Beams are spaced 5 ft o.c.
4. Lateral bracing provided at anchors and at horizontals
5. Alloy: 6063-T5
6. Structure type: building

REQUIRED:

Check the given I-beam's ability to carry the wind load safely.

SOLUTION:

From Part VI, Beam Formulas Case 36, continuous beam of two equal spans-uniformly distributed load:

$$\text{Load, } w = (26.3\text{ lb/ft}^2)(5\text{ ft})(1\text{ ft/12 in.}) = 11.0\text{ lb/in. (positive and negative)}$$

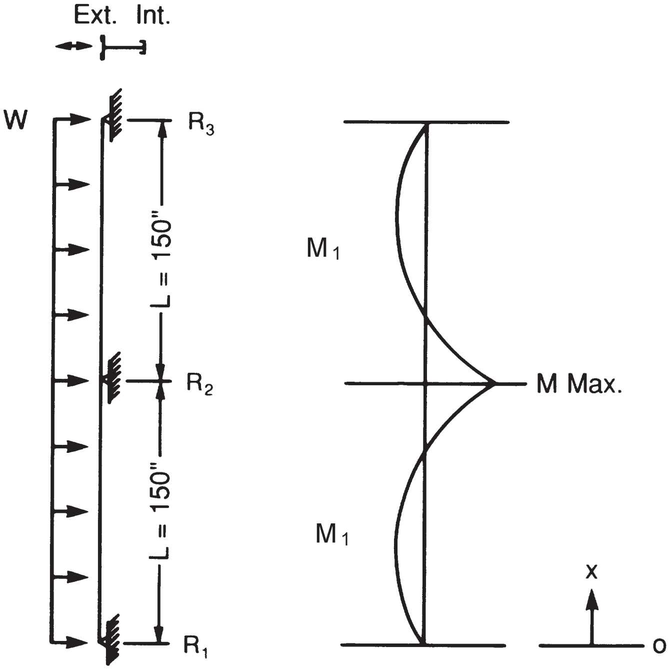


Figure 28a

At any point x between supports 1 and 2,

$$M(x) = R_1x - \frac{wx^2}{2}$$

$$= \left(\frac{3}{8}\right)wLx - \frac{wx^2}{2}$$

$$M_{\max} = \frac{wL^2}{8}$$

$$M_1 = \frac{9}{128}wL^2$$

Since the loadings and support conditions are identical in spans 1 and 2, only span 1 will be reviewed.

Since the load acts both inward and outward, four possible failure modes exist. These include failure due to:

For the interior flange:
1. extreme fiber tensile stress
2. extreme fiber compressive stress

For the exterior flange:
3. extreme fiber tensile stress
4. extreme fiber compressive stress

1. First consider pressure (inward) loadings:

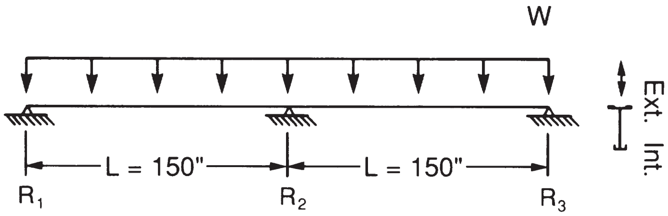


Figure 28b

(A) Consider extreme fiber tensile stresses:

Conservatively use the lesser of allowable tensile bending stresses for the web and flange elements. From Part VI, Table 2-20, Section F.8.1.1

$$F_b = 9.7\text{ ksi}$$

For the beam, the maximum moment occurs at support 2:

$$M_{\max} = \frac{wL^2}{8} = \frac{(11.0)(150)^2}{8} = 30{,}940\text{ in.-lb}$$

This results in the maximum extreme fiber tensile stress, which occurs in the exterior flange:

$$f_b = \frac{Mc}{I} = \frac{(30.94)(6.00 - 3.05)}{11.28} = 8.1 \text{ ksi} < F_b;$$

therefore, it is satisfactory.

(B) Consider extreme fiber compressive stresses:

Allowable compressive stresses are a function of the unbraced length (L_b) and the compression flange geometry. Compressive stresses must therefore be reviewed at the various combinations of moment and unbraced length.

Span	L_b (in.)	$M_{\max}$ (in.-lb)	Compression flange
0′ to 2′	24	11,680	Exterior
2′ to 10′–6″	102	17,400	Exterior
10′–6″ to 12′–6″	24	30,940	Interior

(1) From 0′ to 2′: To determine the slenderness ratio $\frac{L_b}{r_y\sqrt{C_b}}$, the bending coefficient C_b may be conservatively taken as 1:

$$\frac{L_b}{r_y} = \frac{24}{0.84} = 28.6$$

From Section F.2.1,

$$F_b/\Omega = 10.5 - 0.036(28.6) = 9.5 \text{ ksi}$$

$$f_b = \frac{Mc}{I} = \frac{(11.68)(6.00 - 3.05)}{11.28} = 3.05 \text{ ksi} < F_b/\Omega;$$

therefore it is satisfactory.

(2) From 2′ to 10′–6″: To determine the slenderness ratio $\frac{L_b}{r_y\sqrt{C_b}}$, the bending coefficient C_b may be conservatively taken as 1:

$$\frac{L_b}{r_y} = \frac{102}{0.84} = 121.4$$

From Section F.2.1,

$$F_b/\Omega = \frac{87{,}000}{(121.4)^2} = 5.9 \text{ ksi}$$

$$f_b = \frac{Mc}{I} = \frac{(17.4)(6.00 - 3.05)}{11.28} = 4.6 \text{ ksi} < F_b/\Omega;$$

therefore it is satisfactory.

(3) From 10′–6″ to 12′–6″: To determine the slenderness ratio $\frac{L_b}{r_y\sqrt{C_b}}$, the bending coefficient C_b may be conservatively taken as 1:

$$\frac{L_b}{r_y} = \frac{24}{0.50} = 48$$

From Section F.2.1,

$$F_b/\Omega = 10.5 - 0.036(48) = 8.8 \text{ ksi}$$

$$f_b = \frac{Mc}{I} = \frac{(30.94)(3.05)}{11.28} = 8.4 \text{ ksi} < F_b/\Omega;$$

therefore it is satisfactory.

2. Next, consider suction (outward) loadings:

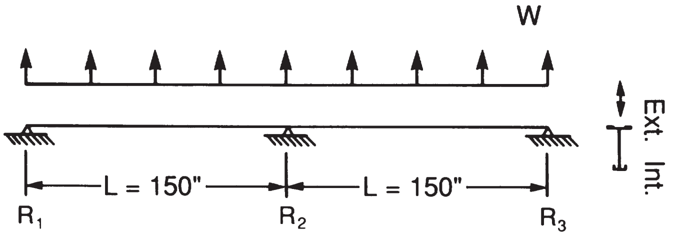


Figure 28c

(A) Extreme fiber tensile stresses are similar to those under pressure loading, therefore, it is satisfactory by inspection

(B) Consider extreme fiber compressive stresses:

Span	L_b (in.)	$M_{\max}$ (in.-lb)	Compression flange
0′ to 2′	24	11,680	Interior
2′ to 10′–6″	102	17,400	Interior
10′–6″ to 12′–6″	24	30,940	Exterior

(1) From 0′ to 2′: To determine the slenderness ratio $\frac{L_b}{r_y\sqrt{C_b}}$, the bending coefficient C_b may be conservatively taken as 1:

$$\frac{L_b}{r_y} = \frac{24}{0.50} = 48$$

From Section F.2.1, $F_b/\Omega = 8.8$ ksi

$$f_b = \frac{Mc}{I} = \frac{(11.68)(3.05)}{11.28} = 3.2 \text{ ksi} < F_b/\Omega;$$

therefore, it is satisfactory.

(2) From 2′ to 10′–6″:

To calculate the slenderness ratio $\frac{L_b}{r_y\sqrt{C_b}}$, the bending coefficient C_b must be calculated. To calculate C_b, determine the moments at the quarter-point, midpoint, and three-quarter point of the span from 2′ to 10′–6″, in accordance with Section F.1.1.1:

location	x	moment (in.-lb)	$\frac{3wLx}{8}-\frac{wx^2}{2}$
quarter-point	49.5	17,100	$= M_A$
midpoint	75	15,400	$= M_B$
three-quarter point	100.5	6,600	$= M_C$

$$M_{\max} = \frac{9wL^2}{128} = 17{,}400 \text{ in-lb}$$

$$C_b = \frac{12.5M_{\max}}{2.5M_{\max} + 3M_A + 4M_B + 3M_C}$$

$$= \frac{12.5(17400)}{2.5(17400) + 3(17100) + 4(15400) + 3(6600)}$$

$$C_b = 1.23$$

$$\frac{L_b}{r_y\sqrt{C_b}} = \frac{102}{0.50\sqrt{1.23}} = 183.9$$

From Section F.2.1,

$$F_b/\Omega = \frac{87{,}000}{(183.9)^2} = 2.6 \text{ ksi}$$

$$f_b = \frac{Mc}{I} = \frac{(17.4)(3.05)}{11.28} = 4.7 \text{ ksi} > F_b/\Omega;$$

therefore it is not satisfactory.

Redetermine the allowable stress using the effective r_y from Section F.2.2.1. This allows use of equation F.2-2:

$$r_{ye} = \frac{1}{1.7}\sqrt{\frac{I_y d}{S_c}\left[\pm 0.5 + \sqrt{1.25 + 0.152\left(\frac{J}{I_y}\right)\left(\frac{L_b}{d}\right)^2}\right]}$$

calculated by taking I_y, S_c, and J as though both flanges were the same as the compression flange with the overall depth remaining the same. Because the load is on a flange and acts in a direction away from the shear center, the plus sign in front of "0.5" is to be used (see note 2 below also).

$$r_{ye} = \frac{1}{1.7}\sqrt{\frac{(0.48)6}{3.65}\left[+0.5 + \sqrt{1.25 + 0.152\left(\frac{0.033}{0.48}\right)\left(\frac{(102)}{6}\right)^2}\right]}$$

$$r_{ye} = 0.837 \text{ in.}$$

Alternately, use the provisions of Section F.2.2.3 to determine r_{ye}:

$$r_{ye} = \frac{L_b}{1.2\pi}\sqrt{\frac{M_e}{ES_c}} \qquad \text{(Eq. F.2-3)}$$

$L_b = 102''$, $E = 10{,}100$ ksi

$$S_c = \frac{I_x}{c_x} = \frac{11.28}{3.05} = 3.70 \text{ in}^3$$

$$M_e = AF_{ey}\left[U + \sqrt{U^2 + r_o^2\left(\frac{F_{et}}{F_{ey}}\right)}\right]$$

$A = 1.92$ in^2 (area of full section)

This section is singly symmetric, so Section F.1.1.2 may be applied to determine C_b. The moment of inertia of the compression flange about the y-axis is I_{cy}:

$$I_{cy} = \frac{1}{12}(0.125)(1)^3 + \frac{2}{12}(0.625)(0.375)^3 + 2(0.375)(0.625)\left(\frac{1.75}{2} - \frac{0.375}{2}\right)^2$$

$$I_{cy} = 0.237 \text{ in}^4$$

$$\frac{I_{cy}}{I_y} = \frac{0.237}{0.92} = 0.26 < 0.9, \text{ and } 0.26 > 0.1, \text{ so}$$

$$F_{ey} = \frac{\pi^2 E}{\left(\frac{k_y L_b}{r_y}\right)^2} = \frac{\pi^2(10{,}100)}{\left(\frac{(1.0)(102)}{0.69}\right)^2} = 4.56 \text{ ksi}$$

$$U = C_1 g_o + C_2 j$$

From the commentary for Section F.1.1.2, for continuous beams loaded as shown in the top two cases of Figure CF.1.1, $C_1 = 0.41C_b$ and $C_2 = 0.47C_b$.

So $C_1 = 0.41\,(1.23) = 0.50$ and $C_2 = 0.47(1.23) = 0.58$

g_o = distance from the shear center to the point of application of load

$g_o = 6 - c = 6 - 4.31 = 1.69$ in. (+ since load acts away from the shear center)

$$j = 0.45 d_f\left(\frac{2I_{cy}}{I} - 1\right)\left(1 - \left(\frac{I_y}{I_x}\right)^2\right) \qquad \text{Eq. F.2-8}$$

for singly symmetric sections.

smaller flange area $= A_{fi} = (1)\,(0.125) + 2(0.625)(0.375)$
$= 0.594$ in^2

larger flange area $= A_{fe} = (2)(0.125) + 2(0.375)(0.50)$
$= 0.625$ in^2

$A_{fi}/A_{fe} = 0.594/0.625 = 0.95 > 0.8$, so j may be taken as $-\,y_o = -$ (y coordinate of the shear center)

$y_o = -\,(4.31 - 3.05) = -\,1.26$ in.

Compare this with the more accurately calculated j:

d_f = distance between flange centroids

$d_f = 6 - 0.260 - 0.375/2 = 5.55$ in.

Note: 0.260 is the calculated distance from the extreme fiber of the interior flange to the centroid of the interior flange.

$$j = (0.45)(5.55)[2(0.26) - 1]\left(1 - \left(\frac{0.92}{11.28}\right)^2\right) = -1.20 \text{ in.}$$

Note the two values for j are approximately equal.

$$U = C_1 g_o + C_2 j = (0.50)(1.69) + (0.58)(-1.20)$$

$$U = 0.149 \text{ in.}$$

$$r_o = (r_x^2 + r_y^2 + x_o^2 + y_o^2)^{1/2}$$

$$r_x = 2.42,\ r_y = 0.69,\ x_o = 0,\ y_o = 4.31 - 3.05 = 1.26$$

$$r_o = (2.42^2 + 0.69^2 + 0^2 + 1.26^2)^{1/2} = 2.81 \text{ in.}$$

$$F_{et} = \frac{1}{Ar_o^2}\left(GJ + \frac{\pi^2 E C_w}{L_t^2}\right)$$

$$L_t = 102 \text{ in.},\ G = 3800 \text{ ksi}$$

$$F_{et} = \frac{1}{(1.92)(2.81)^2}\left((3800)(0.0293) + \frac{\pi^2(10{,}100)(6.11)}{(102)^2}\right)$$

$$F_{et} = 11.2 \text{ ksi}$$

Now evaluating the equation for M_e:

$$M_e = AF_{ey}\left[U + \sqrt{U^2 + r_o^2\left(\frac{F_{et}}{F_{ey}}\right)}\right]$$

$$M_e = (1.92)(4.56)\left[0.149 + \sqrt{0.149^2 + 2.81^2\left(\frac{11.2}{4.56}\right)}\right]$$

$$M_e = 39.9 \text{ k-in.}$$

$$r_{ye} = \frac{L_b}{1.2\pi}\sqrt{\frac{M_e}{ES_c}} = \frac{102}{1.2\pi}\sqrt{\frac{39.9}{(10{,}100)(3.70)}}$$

$$r_{ye} = 0.884 \text{ in.}$$

$$\frac{L_b}{r_{ye}\sqrt{C_b}} = \frac{102}{0.884\sqrt{1.23}} = 104$$

From Section F.2.1,

$F_b/\Omega = [10.5 - 0.036(104)] = 6.8$ ksi $> f_b$;
therefore it is satisfactory.

(3) From 10′–6″ to 12′–6″: conservatively take $C_b = 1$

$L_b/r_y = 24/0.84 = 28.6$

From Section F.2.1, $F_b/\Omega = 9.5$ ksi

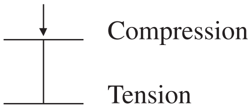
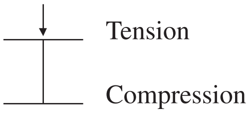
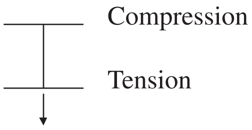
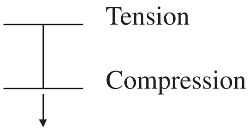
$$f_b = \frac{Mc}{I} = \frac{30.94(2.95)}{11.28} = 8.1 \text{ ksi} < F_b/\Omega;$$

therefore, it is satisfactory.

The given I-beam is therefore satisfactory to carry the required wind load.

NOTES:

1. The equation used for r_{ye} was chosen because the load is applied at the exterior flange. In cases where the load is applied at one of the flanges, the following table can be used to determine the correct sign:

Beam/load combination	Sign
(a) Load promotes buckling	–
  	
(b) Load resists buckling	+
  	

If the load is applied to the web (i.e., near the neutral axis), use the first equation given in Section F.2.2.1.

2. Since the moment is greater between supports than at the ends, C_b can be taken conservatively as 1.0.

3. The beam must also be checked for local buckling. For the flange, Section B.5.4.3, flat elements with one edge supported and one edge with stiffener, applies if $D_s/b < 0.8$; however,

$D_s/b = (0.625 - 0.125)/[(1.75 - 2(0.375) - 0.125)/2]$
$= 0.5/0.4375 = 1.14 > 0.8$,

so Section B.5.4.3 cannot be applied. Using instead Section B.5.4.1, flat elements supported on one edge,

$b/t = (1.75 - 0.125)/2/0.125 = 6.5 < 8.2 = S_1$, so
$F_b/\Omega = 9.7$ ksi

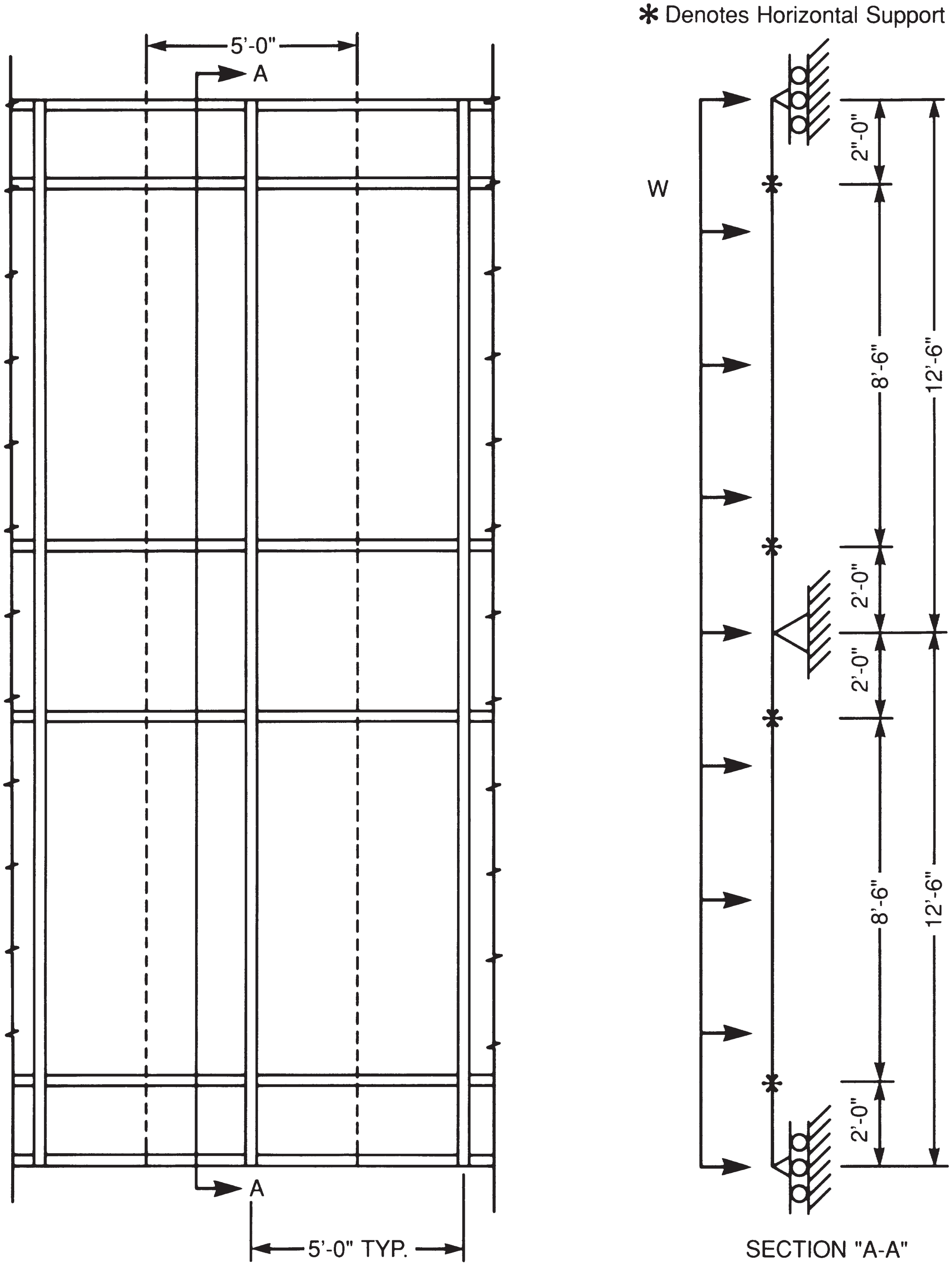
Checking the web (Section B.5.5.1, flat element with both edges supported):

$b/t = (6 - 0.125 - 0.125 - 0.125)/0.125 = 45 < 62.9 = S_1$

So $F_b/\Omega = 12.6$ ksi

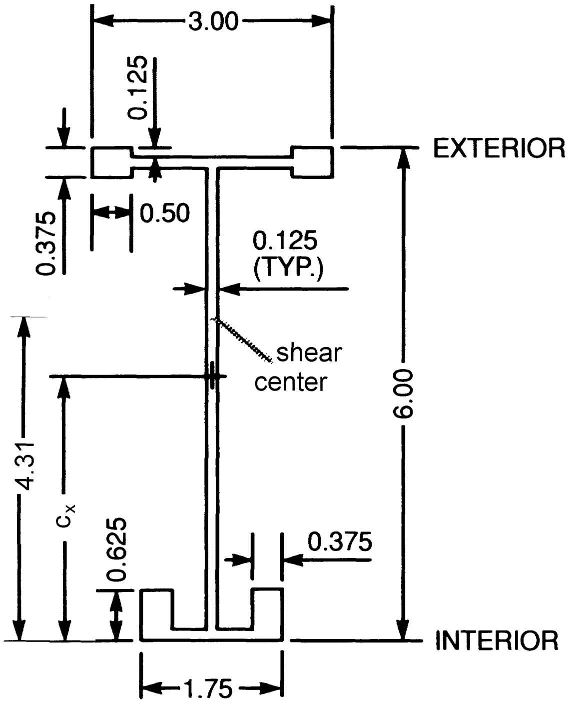
So local buckling does not govern any of the above checks.

4. In order to minimize the calculations shown, some cases not governing were noted to be satisfactory by inspection or were not done. In general, both flanges need to be checked at all critical moment locations (particularly for unsymmetrical sections).



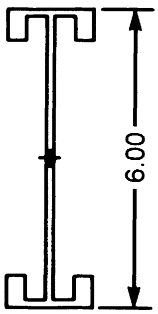
SECTION "A-A"

Figure 28d



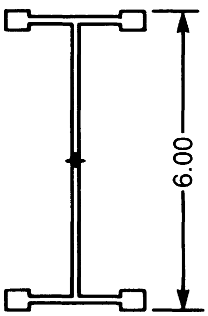
PROPERTIES	
A	1.92 in^2
I_x	11.28 in^4
c_x	3.05 in.
r_x	2.42 in.
I_y	0.92 in^4
r_y	0.69 in.
J	0.0293 in^4
C_w	6.11 in^6

Interior Flange — Properties
(Equivalent Symmetrical Section)



AREA		1.91
I	X-X	10.94
S	X-X	3.65
r	X-X	2.40
I	Y-Y	0.48
r	Y-Y	0.50
J		0.0331

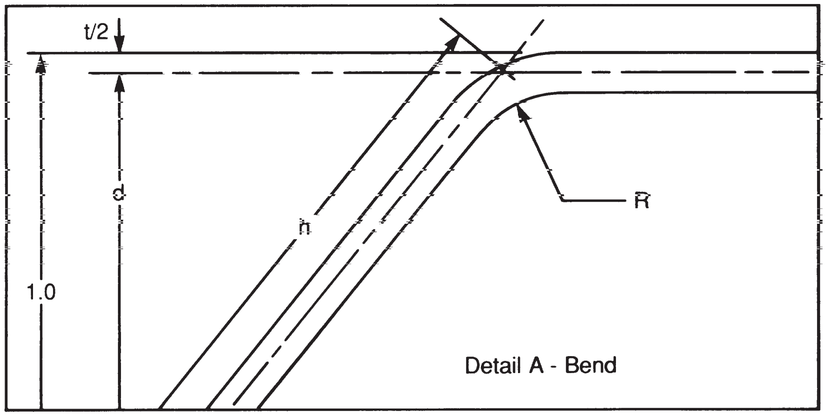
Exterior Flange — Properties
(Equivalent Symmetrical Section)



AREA		1.94
I	X-X	11.63
S	X-X	3.88
r	X-X	2.45
I	Y-Y	1.36
r	Y-Y	0.84
J		0.0255

Figure 28e

Example 29
FORMED SHEET IN BENDING
Illustrating Sections B.5.4.2, B.5.5.1, F.8.3, J.8.1, L.3 and 1.4



Bend Detail

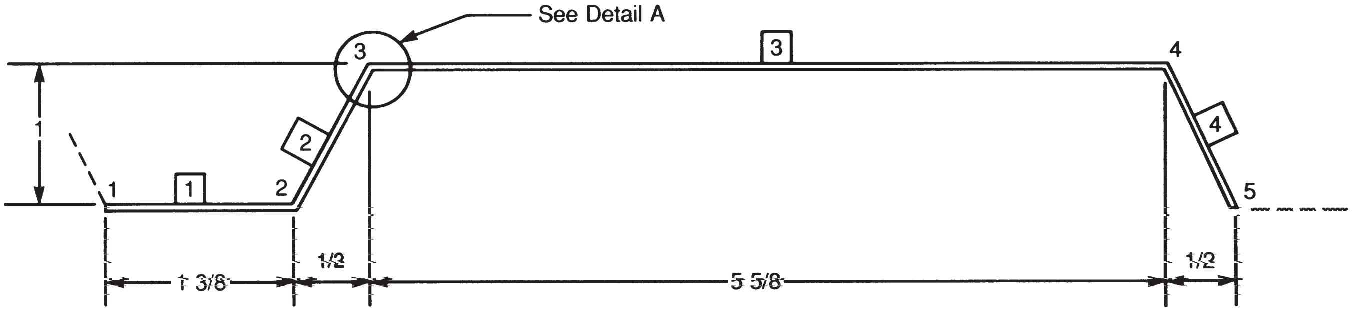


Figure 29

GIVEN:

1. 8 in. rib panel, repeating pattern.
2. Thickness = 0.032 in.
3. Alclad 3004-H151 ($F_{cy} = 28$ ksi, $F_{tu} = 34$ ksi, $F_{ty} = 30$ ksi) (Table A.3.4).
4. Bend radii are 0.0625 in. at inner surface of each bend.
5. Structure type: building

REQUIRED:

1. Allowable bending moments for:
   a. top in compression
   b. bottom in compression
2. Moment of inertia for deflection calculations
3. Allowable reactions:
   a. interior
   b. exterior
4. Check the applicability of calculations for the above against the criteria of Section 1.4.

SOLUTION:

1. Allowable bending moments for:
   a. top in compression
   b. bottom in compression

This siding is the 8″ ribbed siding shown in Part V Table 25 with section properties given in Part V Table 26.

Calculations of Section Properties

The small radii are ignored. Nodal geometry is based on points of intersection of centerlines of elements.

Nodal geometry

Node	x	y
1	0.000	0.016
2	1.375	0.016
3	1.875	0.984
4	7.500	0.984
5	8.000	0.016

Element Properties

Element	y	L	yL	y^2L	I
1	0.016	1.375	0.022	0.000	0.000
2	0.500	1.090	0.545	0.272	0.085
3	0.984	5.625	5.535	5.446	0.000
4	0.500	1.090	0.545	0.272	0.085
Totals		9.179	6.647	5.992	0.170

$c_t = \Sigma yL/\Sigma L = 6.647/9.179 = 0.724$ in., height of neutral axis

$$I_x = [\Sigma(y^2L) - c_t^2\Sigma L + \Sigma I]t = [5.992 - (0.724)^2(9.179) + 0.170](0.032) = (1.349 \text{ in}^3)(0.032 \text{ in.})$$

$$I_x = 0.0432 \text{ in}^4$$

$$S_{\text{bot}} = I_x/c_t = (0.0432)/(0.724) = 0.0596 \text{ in}^3$$

$$S_{\text{top}} = I_x/(\text{height} - c_t) = (0.0432)/(1 - 0.724) = 0.1565 \text{ in}^3$$

The moment of inertia of the flanges (elements 1 and 3) is

$$I_f = [(1.375)(0.724 - 0.016)^2 + (5.625)(0.984 - 0.724)^2](0.032) = 0.0342 \text{ in}^4$$

The moment of inertia of the webs (elements 2 and 4) is

$$I_w = [2(1.090)(0.724 - 0.5)^2 + 2(0.085)](0.032) = 0.0089 \text{ in}^4$$

Allowable compressive stresses

Allowable compressive stresses are determined for each element using the appropriate section of the Specification. For example, for element 3, Section B.5.4.2 applies (flat element in uniform compression).

$b/t = 5.625/0.032 = 175.8$

Since $b/t > S_2 = 41$,

$$F/\Omega = \frac{k_2\sqrt{B_pE}}{(1.6b/t)\Omega} = \frac{2.04\sqrt{(39.3)(10{,}100)}}{1.6(175.8)(1.65)}$$

$$= 2.8 \text{ ksi}$$

The table below summarizes results for all elements.

Element	Length	Spec.	*b/t*	Allowable Compressive Stress (ksi)
1	1.375	B.5.4.2	43.0	11.3
2	1.090	B.5.5.1	34.0	22.1
3	5.625	B.5.4.2	175.8	2.8
4	1.090	B.5.5.1	34.0	22.1

Allowable tension stresses

For elements in uniform tension, the allowable tensile stress

$= \text{lesser of } (F_{ty}/1.65, F_{tu}/1.95)$
$= \text{lesser of } (30/1.65, 34/1.95)$
$= \text{lesser of } (18.2, 17.4)$
$= 17.4$ ksi

For elements in flexural tension, the allowable tensile stress

$= \text{lesser of } (1.3F_{ty}/1.65, 1.42F_{tu}/1.95)$
$= \text{lesser of } ((1.3)(30)/1.65, 1.42)(34)/1.95)$
$= \text{lesser of } (23.6, 24.8)$
$= 23.6$ ksi

Allowable Moments

Weighted average allowable moments are determined from Section F.8.3.

For the top in compression and the bottom in tension: The allowable moment for compression is

$$M_{actc} = (2.8)(0.0342)/(0.984 - 0.724) + (22.1)(0.0089)/(1 - 0.032 - 0.724)$$

$$= 1.17 \text{ in-k}$$

The allowable moment for tension is

$$M_{attc} = (17.4)(0.0342)/(0.724) + (23.6)(0.0089)/(0.724 - 0.032)$$

$= 1.13$ in-k; since $1.17 > 1.13$, compression governs and $M_{atc} = 1.13$ in-k

For the bottom in compression and the top in tension: The allowable moment for compression is

$$M_{acbc} = (11.3)(0.0342)/(0.724 - 0.016) + (22.1)(0.0089)/(0.724 - 0.032)$$

$$= 0.83 \text{ in-k}$$

The allowable moment for tension is

$$M_{atbc} = (17.4)(0.0342)/(1 - 0.724) + (23.6)(0.0089)/(1 - 0.032 - 0.724)$$

$= 3.0$ in-k; since $0.83 < 3.0$, compression governs and $M_{abc} = 0.83$ in-k

The above results can be converted to allowable moments per foot of width as follows:

$M_{atc} = (1.13)(12 \text{ in./ft.})/(8 \text{ in./cycle})$

$= 1.69$ k-in./ft-width (top in compression)

$M_{abc} = (0.83)(12 \text{ in./ft.})/(8 \text{ in./cycle})$

$= 1.24$ k-in./ft-width (bottom in compression)

2. Moment of inertia for deflection calculations
   Refer to Section L.3

For element 1: $F_e = \dfrac{\pi^2E}{(1.6b/t)^2} = \dfrac{\pi^2(10{,}100)}{(1.6(43))^2} = 21.1 \text{ ksi} > 11.3 \text{ ksi} = f_a$

so the width of element 1 is not reduced for deflection calculations.

For element 3: $F_e = \dfrac{\pi^2 E}{(1.6b/t)^2} = \dfrac{\pi^2(10{,}100)}{(1.6(175.8))^2} = 1.3$ ksi
$< 2.8 \text{ ksi} = f_a$

so the effective width of element 3 is

$$b_e = b\,(F_e/f_a)^{1/2}$$
$$= 5.625\,(1.3/2.8)^{1/2}$$
$$= 3.77 \text{ in.}$$

Similarly, it can be seen that elements 2 and 4 are not reduced. A recalculation of the moment of inertia follows:

Element Properties

Element	y	L	L_{eff}	yL_{eff}	y^2L_{eff}	I_{eff}
1	0.016	1.375	1.375	0.022	0.000	0.000
2	0.500	1.090	1.090	0.545	0.272	0.085
3	0.984	5.625	3.77	3.71	3.65	0.000
4	0.500	1.090	1.090	0.545	0.272	0.085
Totals			7.325	4.822	4.19	0.170

$c_t = \Sigma(yL_{eff})/\Sigma L = 4.822/7.325$
$= 0.658$ in., height of neutral axis
$I_x = [\Sigma(yL^2_{eff}) - c_t^2\Sigma L_{eff} + \Sigma I_{eff}]t = (4.19 - (0.658)^2(7.325) + 0.170)(0.032)$
$= (1.189 \text{ in}^3)(0.032 \text{ in.})$
$= 0.038 \text{ in}^4$, for deflection calculations when element 3 is at its allowable compressive stress.

3. Allowable reactions:
   a. allowable interior reaction
      Reference: Section J.8.1
      Let the bearing length, N, be 2.0 in.
      Consider element 2 (a web).

$$P_c/\Omega = \frac{C_{wa}(N + C_{w1})}{\Omega C_{wb}}$$

where $C_{wa} = t^2 \sin\theta\,(0.46\,F_{cy} + 0.02\,\sqrt{EF_{cy}})$

where $t = 0.032$ in.
$\theta = 63.4°$
$F_{cy} = 28$ ksi
$E = 10{,}100$ ksi
so $C_{wa} = (0.032)^2 \sin 63.4°\,(0.46(28) + 0.02\,\sqrt{(10{,}100)(28)})$
$C_{wa} = 0.0215$ k
$C_{w1} = 5.4$ in.
$C_{wb} = C_{w3} + R_i\,(1 - \cos\theta)$

where $C_{w3} = 0.4$ in.
$R_i = 0.0625$ in.
so $C_{wb} = 0.4 + 0.0625\,(1 - \cos 63.4°)$
$C_{wb} = 0.435$ in.
so $P_c/\Omega = \dfrac{(0.0215)(2.0 + 5.4)}{(1.95)(0.435)} = 0.188$ k per web

The allowable interior reaction, F_{int} is

$F_{int} = (P_c/\Omega)$(2 webs/cycle)(12 in./ft.)(1 cycle/8 in.)(1000lb/k)
$= 563$ lb/ft-width.

Section J.8.3, combined web crippling and bending, should also be considered.

   b. Allowable end reaction
      Let the bearing length, N, be 2.0 in.
      Again, consider element 2.

$$P_c/\Omega = \frac{1.2C_{wa}(N + C_{w2})}{\Omega C_{wb}}$$

where $C_{wa} = 0.0215$ k [see (a) above]
$C_{w2} = 1.3$ in.
$C_{wb} = 0.435$ in. [see (a) above]

$$P_c/\Omega = \frac{1.2(0.0215)(2.0 + 1.3)}{(1.95)(0.435)} = 0.100 \text{ k per web.}$$

The allowable end reaction, P_{end}, is:

$P_{end} = (P_c/\Omega)$(2 webs/cycle)(12 in./ft.)(1 cycle/8 in.)(1000 lb/k)
$= 301$ lb/ft-width

4. Check the applicability of calculations for the above against the criteria of Section 1.4.

Cases (a), (b), and (e) do not apply. Cases (c), (f), and (g) vary with each installation.

Case (d) is checked as follows:

maximum $b = 5.625 + 2(0.25)$
$= 6.125$ in.
$b/t = 6.125/0.032$
$= 191$

Condition (1) is stated then algebraically rearranged.

(1) $b/t < \dfrac{1230}{\sqrt[3]{q}}$ otherwise tests are required.

$q < (1230/(b/t))^3$
$q < 265$ psf

Condition (2) is treated likewise

(2) $b/t < 435\,\sqrt{F_{ty}/q}$ otherwise tests are required.

$q < [435/(b/t)]^2 F_{ty}$
$q < [435/191]^2(30)$
$q < 155$ psf

Subcase (2) governs. Tests must be run to establish the load carrying capacity of the panel when:

a. $q > 155$ psf

b. Cases (c), (f), or (g) are not satisfied.

Example 30
SCREW CONNECTION
Illustrating Section J.5

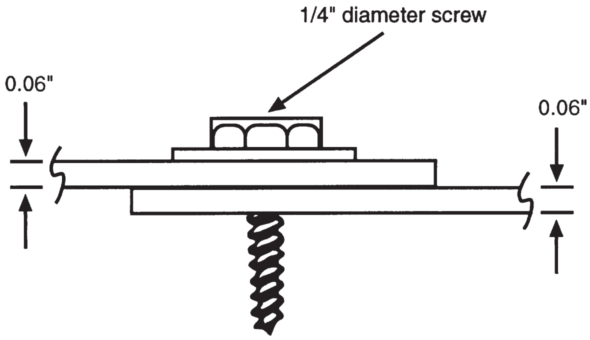


Figure 30

GIVEN:

1. Tapping screw of 7075-T73 aluminum, ¼″ diameter, UNC thread joining 0.06 in. thick 3003-H16 sheet on top of 0.06 in. thick 5052-H32 sheet.
2. ⅝″ outside diameter flat washer under the screw head.
3. The hole diameter in the top sheet is 9⁄32″.
4. Distance from center of screw to edge of sheet is 1 in.
5. Structure type: building

REQUIRED:

The allowable shear and tension forces for the connection.

SOLUTION:

1. Allowable shear force

   The allowable connection shear is determined according to Section J.5.6, which specifies a safety factor $\Omega = 3.0$ for screw connection shear for building-type structures.

   a) Section J.5.6.1 addresses bearing. Since the edge distance is 1 in. > 0.5 in. = 2(¼ in.) = $2D$, the allowable bearing force is $2F_{tu}Dt/\Omega$. Using F_{tu} from Table A.3.4, the allowable shear for bearing is

Sheet	Alloy	Thickness (in.)	F_{tu} (ksi)	$2F_{tu}Dt/\Omega$ (k)
1	3003-H16	0.06	24	0.24
2	5052-H32	0.06	31	0.31

   b) Section J.5.6.2 addresses screw tilting. Since $t_2 = 0.06 \le 0.06 = t_1$, the allowable screw tilting shear is

$$R_n/\Omega = 4.2(t_2^3D)^{1/2}F_{tu2}/\Omega = 4.2(0.06^3 \times 0.25)^{1/2}(31)/3$$
$$= 0.32 \text{ k}$$

   c) Section J.5.6.3 addresses screw shear. The single shear strength of a ¼″ 7075-T73 machine screw is given in Part VI, Table 5-1 as 1170 lb.

$$R_n/(1.25\Omega) = (1170 \text{ lb})/(1.25(3)) = 0.31 \text{ k}$$

   The allowable shear is the least of 0.24, 0.31, 0.32, and 0.31 k, so the allowable shear is 0.24 k based on bearing on the top sheet.

2. Allowable tensile force

   The allowable connection tension is determined according to Section J.5.5, which specifies a safety factor $\Omega = 3.0$ for screw connection tension for building-type structures.

   Section J.5.5 requires that the washer outside diameter D_w equal or exceed 5⁄16 in.:

$$D_w = 5/8 \text{ in.} > 5/16 \text{ in.}$$

   a) Section J.5.5.1 addresses pull-out. The allowable pull-out force is

$$R_n/\Omega = K_sDL_eF_{ty2}/\Omega$$
$$= (1.01)(0.25)(0.06)(23)/3 = 0.12 \text{ k}$$

   b) Section J.5.5.2 addresses pull-over. The allowable pull-over force is:

$$R_n/\Omega = C_{pov}t_1F_{tu1}(D_{ws} - D_h)/\ \Omega$$
$$= (1.0)(0.06)(24)(0.625 - 9/32)/3$$
$$= 0.16 \text{ k}$$

   c) Section J.5.5.3 addresses screw tension. The tensile strength of a ¼″ diameter 7075-T73 machine screw is given in Part VI, Table 5-1 as 1940 lb.

$$R_n/(1.25\Omega) = (1940 \text{ lb})/(1.25(3)) = 0.52 \text{ k}$$

The allowable tension is the least of 0.12, 0.16, and 0.52 k, so the allowable tension is 0.12 k based on pull-out.

Example 31
WEIGHTED AVERAGE BENDING STRENGTH
Illustrating Section F.8.3

GIVEN:

1. Symmetric Shape: Aluminum Association standard I 12 × 14.3

d	12″
b_f	7″
t_f	0.62″
t_w	0.31″
S_x	52.9 in^3
web height h	10.76″ = 12″ – 2(0.62″)
flange area	7(0.62) = 4.34 in^2
web area	10.76(0.31) = 3.34 in^2

Unsymmetric Shape: Modified I 12 × 14.3 (top flange 1″ wide instead of 7″ wide)

d	12″
b_f (bottom)	7″
b_f (top)	1″
t_f	0.62″
t_w	0.31″
web height h	10.76″ = 12″ – 2(0.62″)
bottom flange area	7(0.62) = 4.34 in^2
top flange area	1(0.62) = 0.62 in^2
web area	10.76(0.31) = 3.34 in^2

2. Alloy: 6061-T6
3. Continuous minor axis lateral bracing
4. Structure type: building

REQUIRED:

The allowable bending moment about the major axis for each shape for loading causing compression in the top flange

SOLUTION:

Allowable stresses for 6061-T6 given in Part VI Table 2-19 are used below.

Symmetric Shape: Aluminum Association standard I12 × 14.3:

Compression
Section B.5.4.1: Flange: $b/t = (7'' - 0.31'')/2/(0.62'') = 5.4 < 6.7 = S_1$, so $F_c/\Omega = 21.2$ ksi
Section B.5.5.1: Web: $b/t = (10.76'')/(0.31'') = 34.7 < 49.3 = S_1$, so $F_b/\Omega = 27.6$ ksi

Tension
Section F.8.1.1: Flange: $F_t/\Omega = 19.5$ ksi
Section F.8.1.2: Web: $F_b/\Omega = 27.6$ ksi

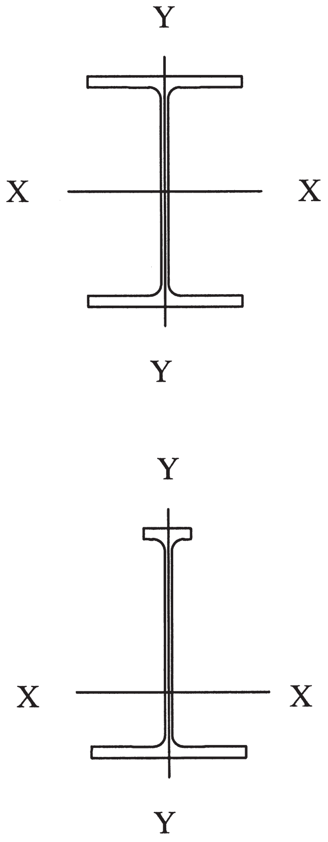


Figure 31

$$I_f = 2[(7'')(0.62'')^3/12 + (7'')(0.62'')(6'' - 0.62''/2)^2]$$
$$= 281.3 \text{ in}^4$$
$$c_{cf} = 12''/2 - (0.62''/2) = 5.69''$$
$$c_{tf} = 12''/2 = 6''$$
$$I_w = (0.31'')(10.76'')^3/12 = 32.2 \text{ in}^4$$
$$c_{cw} = c_{tw} = 10.76''/2 = 5.38''$$

From Section F.8.3, the allowable bending moments are:

$$M_{ac} = \frac{(F_c/\Omega)I_f}{c_{cf}} + \frac{(F_b/\Omega)I_w}{c_{cw}} = \frac{(21.2)(281.3)}{5.69} + \frac{(27.6)(32.2)}{5.38}$$
$$= 1213 \text{ in-k}$$

$$M_{at} = \frac{(F_t/\Omega)I_f}{c_{tf}} + \frac{(F_b/\Omega)I_w}{c_{tw}} = \frac{(19.5)(281.3)}{6} + \frac{(27.6)(32.2)}{5.38}$$
$$= 1079 \text{ in-k}$$

The allowable bending moment is the lesser of M_{ac} and M_{at}, which is $M_{at} = 1079$ in-k.

Unsymmetric Shape: Modified I 12 × 14.3 (top flange 1″ wide):

Determine moment of inertia:

	A	y	Ay	d	Ad^2	I	$Ad^2 + I$
bottom flange	4.34	11.69	50.73	3.14	42.79	0.14	42.93
web	3.34	6	20.04	2.55	21.72	32.18	53.9
top flange	0.62	0.31	0.19	8.24	42.10	0.02	42.12
total	8.3		70.96		106.61	32.34	139

The neutral axis is located (70.96 in^3)/(8.3 in^2) = 8.55″ below the top of the section.

Compression
Section B.5.4.1: Flange: $b/t = (1'' - 0.31'')/2/(0.62'') = 0.6 < 6.7 = S_1$, so $F_c/\Omega = 21.2$ ksi
Section B.5.5.1: Web: $b/t = (10.76'')/(0.31'') = 34.7$

The neutral axis is located 8.55″ – 0.62″ = 7.93″ below top end of web and 10.76″ – 7.93″ = 2.83″ above bottom of web.

$c_o/c_c = 2.83/(-7.93) = -0.36$, so $m = 1.15 + (-0.36)/2 = 0.97$.

$S_1 = (B_{br} - 1.3F_{cy})/(mD_{br}) = (66.8 - 1.3(35))/[(0.97)(0.665)] = 33 < 34.7 = b/t$, so $F_b/\Omega = B_{br}/\Omega - mD_{br}(b/t)/\Omega = 66.8/1.65 - 0.97(0.665)(34.7)/1.65 = 26.9$ ksi

Tension
Section F.8.1.1: Flange: $F_t/\Omega = 19.5$ ksi
Section F.8.1.2: Web: $F_b/\Omega = 27.6$ ksi

$I_f = 42.93 + 42.12 = 85.05\ \text{in}^4$
$c_{cf} = 8.55'' - 0.62''/2 = 8.24''$
$c_{tf} = 12'' - 8.55'' = 3.45''$
$I_w = 53.9\ \text{in}^4$
$c_{cw} = 7.93''$
$c_{tw} = 2.83''$

From Section F.8.3, the allowable bending moments are:

$$M_{ac} = \frac{(F_c/\Omega)I_f}{c_{cf}} + \frac{(F_b/\Omega)I_w}{c_{cw}} = \frac{(21.2)(85.05)}{8.24} + \frac{(26.9)(53.9)}{7.93} = 402 \text{ in-k}$$

$$M_{at} = \frac{(F_t/\Omega)I_f}{c_{tf}} + \frac{(F_b/\Omega)I_w}{c_{tw}} = \frac{(19.5)(85.05)}{3.45} + \frac{(27.6)(53.9)}{2.83} = 1006 \text{ in-k}$$

The allowable bending moment is the lesser of M_{ac} and M_{at}, which is $M_{ac} = 402$ in-k.

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Appendix 1

SI Guide

Appendix 1
SI Guide

Table A.1
SI CONVERSION FACTORS

Quantity	Multiply		By	To obtain	
Length	inch	in.	25.400	millimeter	mm
	foot	ft	0.3048	meter	m
	mile	mi	1.609	kilometer	km
	millimeter	mm	0.03937	inch	in.
	meter	m	3.281	foot	ft
	kilometer	km	0.621	mile	mi
Area	square inch	in^2	645.16	square millimeter	mm^2
	square foot	ft^2	0.093	square meter	m^2
	square mile	mi^2	2.590	square kilometer	km^2
	square millimeter	mm^2	0.001550	square inch	in^2
	square meter	m^2	10.764	square foot	ft^2
	square kilometer	km^2	0.386	square mile	mi^2
Volume	cubic inch	in^3	16387	cubic millimeter	mm^3
	cubic foot	ft^3	0.028317	cubic meter	m^3
	cubic yard	yd^3	0.765	cubic meter	m^3
	gallon (U.S. liquid)	gal	3.785	liter	L
	quart (U.S. liquid)	qt	0.946	liter	L
	cubic millimeter	mm^3	61.024×10^{-6}	cubic inch	in^3
	cubic meter	m^3	35.315	cubic foot	ft^3
	cubic meter	m^3	1.308	cubic yard	yd^3
	liter	L	0.2642	gallon (U.S. liquid)	gal
	liter	L	1.057	quart (U.S. liquid)	qt
Mass	ounce	oz	28.350	gram	g
	pound	lbm	0.4536	kilogram	kg
	short ton (2,000 lb)		907.2	kilogram	kg
	gram	g	0.035274	ounce	oz
	kilogram	kg	2.205	pound	lbm
	kilogram	kg	0.001102	short ton (2,000 lb)	
Force	pound-force	lbf	4.448	newton	N
	kip	k	4.448	kilonewton	kN
	newton	N	0.2248	pound-force	lbf
	kilonewton	kN	0.2248	kip	k

Table A.1
SI CONVERSION FACTORS (Continued)

Quantity	Multiply		By	To obtain	
Bending Moment	pound-force-inch	lbf-in.	0.113	newton-m	N-m
	pound-force-ft	lbf-ft	1.356	newton-m	N-m
	newton-m	N-m	8.851	pound-force-inch	lbf-in.
	newton-m	N-m	0.738	pound-force-ft	lbf-ft
Stress, Pressure	pound-force per square inch	lbf/in^2	6.895	kilopascal	kPa
	pound-force per square foot	lbf/ft^2	0.04788	kilopascal	kPa
	inch of water	in. w.c.	0.249	kilopascal	kPa
	kip per square inch	k/in^2	6.895	megapascal	MPa
	kilopascal	kPa	0.145	pound-force per square inch	lbf/in^2
	kilopascal	kPa	20.885	pound-force per square foot	lbf/ft^2
	kilopascal	kPa	4.015	inch of water	in. w.c.
	megapascal	MPa	0.145	kip per square inch	k/in^2
Energy, Work, Heat	foot-pound-force	ft-lbf	1.356	joule	J
	British thermal unit	Btu	1055	joule	J
	calorie	cal	4.187	joule	J
	kilowatt-hour	kW-h	3.600×10^6	joule	J
	joule	J	0.738	foot-pound-force	ft-lbf
	joule	J	0.948×10^{-3}	British thermal unit	Btu
	joule	J	0.239	calorie	cal
	joule	J	0.278×10^{-6}	kilowatt-hour	kW-h
Density	pound per cubic foot	lb/ft^3	16.0185	kilogram per cubic meter	kg/m^3
	kilogram per cubic meter	kg/m^3	0.06243	pound per cubic foot	lb/ft^3
Angle	degree	deg	0.017453	radian	rad
	radian	rad	57.296	degree	deg
Temperature	°C = (°F – 32)/1.8				
	°F = 1.8°C + 32				

See ASTM E 380 for more information.

Table A.2
SI PREFIXES

Multiplication Factor	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto[a]	h
10^{1}	deka[a]	da
10^{-1}	deci[a]	d
10^{-2}	centi[a]	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

a: not recommended

Table A.3
SI DERIVED UNITS WITH SPECIAL NAMES

Quantity	Unit	Symbol	Formula
force	newton	N	kg-m/s^2
pressure, stress	pascal	Pa	N/m^2
energy, work	joule	J	N-m
power	watt	W	J/s

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